

JPL Publication 90-3

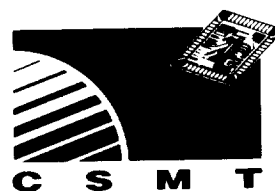
# Center for Space Microelectronics Technology

## 1988-1989 Technical Report



National Aeronautics and  
Space Administration

**Jet Propulsion Laboratory**  
California Institute of Technology  
Pasadena, California



The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration, Strategic Defense Initiative Organization/Innovative Science and Technology Office, Defense Advanced Research Projects Agency, U. S. Army, U. S. Navy, U. S. Air Force and U. S. Department of Energy.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government, or the Jet Propulsion Laboratory, California Institute of Technology.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

## Abstract

The 1988-1989 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the center during the past two years. The report lists 321 publications, 282 presentations, and 140 new technology reports and patents.



TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. JPL Publication 90-3		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Center for Space Microelectronics Technology 1988-1989 Technical Report				5. Report Date March 1, 1990	
				6. Performing Organization Code	
7. Author(s) Peggy Olsen				8. Performing Organization Report No.	
9. Performing Organization Name and Address  JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91109				10. Work Unit No.	
				11. Contract or Grant No. NAS7-918	
				13. Type of Report and Period Covered  JPL Publication	
12. Sponsoring Agency Name and Address  NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546				14. Sponsoring Agency Code (c/c)B-055-80-08-00-20	
15. Supplementary Notes					
16. Abstract  The 1988-1989 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the center during the past two years. The report lists 321 publications, 282 presentations, and 140 new technology reports and patents.					
17. Key Words (Selected by Author(s))  Computer Programming and Software Infrared and Ultraviolet Detection Optics Solid-State Physics				18. Distribution Statement  Unclassified -- Unlimited	
19. Security Classif. (of this report)  Unclassified		20. Security Classif. (of this page)  Unclassified		21. No. of Pages  123	
				22. Price	



## Table of Contents

Director's Report .....	1
Microdevices Laboratory .....	5
I. Solid State Devices .....	9
Overview .....	11
1988-1989 Major Technical Achievements .....	11
Technical Progress Reports	
Electron Tunneling .....	15
Superconductivity .....	20
Submillimeter (Terahertz) Receiver Technology .....	24
Semiconducting Materials: Growth and Characterization .....	27
Electronic Device Technology .....	34
Molecular Electronics .....	36
II. Photonics .....	39
Overview .....	41
1988-1989 Major Technical Achievements .....	41
Technical Progress Reports	
Spatial Light Modulators .....	45
Lasers .....	47
Optoelectronic Materials and Characterization .....	51
Optoelectronic Integrated Circuits .....	54
Infrared Detectors .....	55
Nonlinear Optical Materials and Characterization .....	58
Fiber Optics .....	63
Photovoltaic Technology .....	64
III. Computer Architecture and Subsystems .....	67
Overview .....	69
1988-1989 Major Technical Achievements .....	69
Technical Progress Reports	
Parallel Computation .....	76
Neural and Analog Computing .....	85
Neural and Nonlinear Theory .....	90
Optical Processing .....	98

Data Storage .....	101
Molecular Computation .....	103
<b>IV. Custom Microcircuits.....</b>	<b>105</b>
Overview.....	107
1988-1989 Major Technical Achievements.....	107
Technical Progress Reports	
Application Specific Integrated Circuits.....	109
Quality Assurance and Space Qualification Methodology.....	111
Algorithms Tailored for ASIC Design .....	114
<b>V. Appendix.....</b>	<b>117</b>
• CSMT-Caltech Campus Collaboration .....	119
• Distinguished Visiting Scientists.....	120
• Conferences and Workshops .....	123
 Figure	
MDL First Floor.....	7



## Director's Report

The Center for Space Microelectronics Technology (CSMT) was established in 1987 at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (Caltech). The CSMT's mission is to perform research and advanced development in the area of microelectronics to support new space missions for the National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DoD).

The CSMT is chartered to investigate and advance innovative scientific concepts and phenomena, leading to the development of electronic materials and devices that will enable and enhance NASA and DoD space missions. The Center develops and evaluates new electronic and optical concepts for sensors, information processing, data storage, and real-time signal processing. It explores novel concepts in solid state devices for application in space. The Center also develops the technological base required to advance space computing concepts and architectures - in response to the unique requirements of the space environment.

The CSMT Board of Governors provides policy guidance and program oversight for the Center. The Chairman of the Board is the Director of JPL. The Board includes representatives of NASA, the Caltech Campus, and sponsoring agencies who maintain a significant relationship with the CSMT. The CSMT Board of Governors members are:

- Dr. Lew Allen (Chairman), Director, JPL.
- Mr. Arnold D. Aldrich, Associate Administrator, Office of Aeronautics and Space Technology, NASA.
- Dr. Craig I. Fields, Director, Defense Advanced Research Projects Agency (DARPA).
- Dr. Dwight Duston, Director, Innovative Science and Technology Office, Strategic Defense Initiative Organization.
- Dr. Thomas E. Everhart, President, Caltech.
- Dr. Lennard Fisk, Associate Administrator, Office of Space Science and Applications, NASA.
- Dr. Paul Jennings, Vice President and Provost, Caltech.

The CSMT has formed a Scientific Advisory Board (SAB) to advise the CSMT Board of Governors, the CSMT Director, and JPL management on the content and quality of the CSMT technical program. The SAB consists of the following members:

- Dr. Terry Cole, Chief Technologist, JPL (Board Chairman).
- Dr. Bob L. Gregory, Director, Microelectronics/Materials Center, Polaroid Corporation.
- Professor Carver Mead, Department of Computer Science, Caltech.

- Dr. Venkatesh Narayanamurti, Vice President for Research, Sandia National Laboratories.
- Professor John Whinnery, Department of Electrical Engineering and Computer Science, University of California, Berkeley.
- Dr. Jerry Woodall, Thomas J. Watson Research Center, IBM Corporation.

The SAB met twice during the past year to obtain an overview of CSMT activities. The SAB concluded that the facilities and capabilities of the CSMT form a sound combination for space microelectronics research and development work in the future. In addition, the staff was rated as "technically outstanding, enthusiastic, and well versed in [their] fields of specialization." All in all, the findings of the SAB are highly encouraging for the CSMT.

The CSMT encompasses four major research areas: solid state devices, photonics, computer architecture, and custom microcircuits. This Director's Report focuses on recent CSMT activities as well as the more significant achievements of the Center and its staff.

The past year has been a busy and productive time for the CSMT. The Center continues in a leadership role on a number of scientific, programmatic, and institutional fronts at JPL.

## Technical Achievements

On the technical front, the CSMT has actively pursued research in a variety of areas. CSMT scientists and engineers have made great strides in several fields of endeavor, including the following:

- Achievement of breakthrough performance for very long wavelength germanium blocked impurity band (GeBIB) detectors. Initial data indicate high responsivity (4.5 amperes per watt at 100 microns), dark current of less than 1000 electrons per second, and spectral response to 200 microns. The detectors have achieved the far-infrared coverage, quantum efficiency, and dark current performance required by the Space Infrared Telescope Facility (SIRTF) mission.
- Growth and fabrication of CoSi<sub>2</sub> infrared detectors using silicon molecular beam epitaxy and a doping spike thereby increasing the cutoff wavelength from 3.5 to 5.0 microns.
- Demonstration of an InGaAsSb 2.1 micron laser for use in pumping solid state lasers for LIDAR and long-range optical communication.
- Development of nonlinear optical organic materials with second-harmonic efficiency ten times greater than the previous record.
- Design and fabrication of the custom direct memory access controller (DMAC) chip with 55,000 transistors. The design meets flight qualification standards and the initial chip is fully functional. The DMAC is designed for the Mariner Mark II spacecraft computer.
- Processing of Voyager 2 images from Neptune on an eight-node hypercube, with 80 times greater performance than that obtained using a VAX 8600 computer. The images were used for "weather forecasting" of the motion of storms on Neptune, allowing detailed imaging during the close encounter period.

- Discovery and demonstration of a novel neural nets algorithm and architecture to solve computationally intensive problems such as resource allocation and the "Traveling Salesman Problem."
- Demonstration of a niobium nitride-based superconductor (SIS) tunnel junction as a mixer in a 205-GHz heterodyne receiver.

In the area of electron tunneling, William Kaiser's pioneering developments in electron tunneling including invention of ballistic electron emission microscopy (BEEM) (with L.D. Bell) have been rewarded with a NASA Outstanding Scientific Achievement Award. Dr. Heinrich Rohrer, IBM-Zurich Research Laboratory, visited JPL in order to discuss BEEM, which now allows for the study of buried interfaces. Dr. Rohrer was recipient of the 1986 Nobel Prize in Physics for the invention of the scanning tunneling microscope.

## **Programmatic Achievements**

On the programmatic front, the CSMT has coordinated with the NASA Office of Aeronautics and Space Technology, the NASA Langley Research Center, and the NASA Ames Research Center to initiate a research program with AT&T Bell Laboratories on the applicability of multiple quantum well technology for NASA infrared focal plan array needs in the 6- to 17-micron range. Such technology is required for several JPL Earth Observing System (Eos) instruments, including the Atmospheric Infrared Sounder (AIRS).

A new effort in the area of high temperature superconductivity has been initiated within the CSMT by NASA. Brian Hunt's current effort in thin film superconductivity for SDIO/IST and DARPA is augmented. In addition, another effort directed by Donald Strayer focuses on the RF characterization of high temperature superconducting materials.

The U.S. Army Laboratory Command, which includes the Army Laboratories, the Army Research Office, and the Army Space Technology and Research Office, has become a CSMT sponsor. The CSMT program for the Army focuses on ballistic electron devices and millimeter wave imaging.

The CSMT has achieved progress in the transfer of technology to industry in the following areas:

- Electron tunneling accelerometer to the Charles Stark Draper Laboratory;
- Neural network technology to McDonnell Douglas Corporation and TRW;
- Superconducting niobium nitride tunnel-junction wafers for circuit applications to TRW;
- Silicon-compatible infrared detector technology collaboration with Hughes; and,
- Collaborative development of a fault tolerant multiprocessor computer with Unisys.

The CSMT has participated extensively in planning sessions and program reviews for Center sponsors. It is a goal of the Center to have an overview of space microelectronics that includes both civilian and defense needs. CSMT personnel have served on the DARPA neural networks study team, participated in SDIO electronics and signal processing reviews, and worked with NASA to plan initiatives in high performance computing and global change technology. The CSMT Director represents NASA on the

Technical Review Committee for the Joint Services Electronics Program (JSEP). JSEP is an Army, Navy and Air Force program that funds electronics research at thirteen universities. The CSMT Director also served on the NASA team that evaluated proposals by 110 U.S. universities for establishment of NASA Space Engineering Research Centers. Nine universities were awarded centers. The two institutions selected in the area of space microelectronics are:

- The University of Michigan Center for Space Terahertz Technology; and,
- The University of Idaho Center for Custom VLSI for Space Applications.

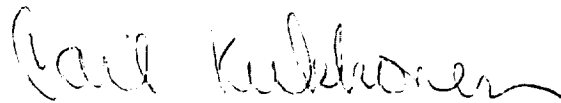
The CSMT is working closely with the University of Michigan Center in a program in which CSMT scientists and Michigan faculty members collaborate in research on a wide range of topics, including quantum well multipliers, varactor multipliers, and quantum well negative resistance tunneling oscillators.

Also on the programmatic front, the CSMT has actively pursued its Distinguished Visiting Scientist (DVS) program, designed to allow outstanding researchers from industry and academia to interact and work with CSMT staff members. Recent DVS participants have included Erik Fossum, Columbia University; James Lukens, State University of New York, Stony Brook; Pieter Balk, Delft Institute of Technology, The Netherlands; Floyd Humphrey, Boston University; James Rosenberg, Brown University; Craig Davis, Ford Motor Company; James Mayer, Cornell University; and Olof Engstrom, Chalmers University, Sweden.

## **Institutional Achievements**

On the Institutional front, the CSMT has several areas of accomplishments to report. Among the most exciting developments is the completion of the state-of-the-art Microdevices Laboratory (MDL); it is described in the following section.

The CSMT, with support from SDIO/Innovative Science and Technology Office, has acquired the JEOL JBX-5DII electron beam lithography system, offering a resolution unsurpassed by any other instrument of its kind. This facility allows the fabrication of devices with feature sizes as small as 15 nm. Structures and devices to be fabricated include quantum size effect dots, nanometer scale superconducting submillimeter wave detectors, a distributed feedback diode laser, and thin film neural network synapses.



---

Carl A. Kukkonen, Director

# Microdevices Laboratory

## Introduction

The new JPL Microdevices Laboratory (MDL), completed in 1989, is the primary facility of the Center for Space Microelectronics Technology (CSMT). It is dedicated to research and advanced development of microelectronic and photonic devices to meet the unique needs of NASA and DOD space missions. The Microdevices Laboratory will also significantly enhance JPL/Caltech campus collaborative research in the fields of electrical engineering and condensed matter physics.

The MDL enables the development of a multitude of advanced space microelectronic devices, such as infrared detectors, millimeter and submillimeter wave detectors, electronic neural network devices, lasers, and optoelectronic integrated circuits. Experimental solid state devices based on silicon, compound semiconductors and superconductors are fabricated and characterized for their electrical, optical and surface/interface properties in the MDL. Technology developed at the MDL will eventually be transferred to industry.

## Building Facilities

The MDL is a 38,000 square foot facility with clean rooms for material deposition, lithography and device processing, and conventional laboratories for characterization. The clean rooms, divided into three categories (classes 10, 100, 1000) are arranged in conventional bays (work areas) and chases for mechanical pumps and utilities. These features are shown in the figure at the end of this section.

Located above the conventional laboratories are two levels of offices which accommodate the 65 scientists, engineers and staff of the MDL. The Microdevices Laboratory is designed to encourage a high level of intellectual synergism, and enable the benefits of sharing key equipment and experienced support staff.

The MDL meets all the Federal, State, and County safety codes and regulations. Toxic and pyrophoric gases are stored in autopurge gas cabinets in a gas bunker. These gases are distributed to the point of use by nitrogen gas-purged coaxial stainless steel pipes; and at the point of use, the valves and regulators are enclosed in exhausted secondary enclosures. Toxic and pyrophoric gases are continuously monitored by a sophisticated safety system that includes seismic sensors, and the MDL staff has received extensive safety training.

## Research Equipment

The materials deposition capabilities of the MDL include silicon and compound semiconductor molecular beam epitaxy (MBE), metalorganic chemical vapor deposition (MOCVD), atomic layer epitaxy (ALE), liquid phase epitaxy (LPE), chemical vapor deposition (CVD) of amorphous silicon, sputtering, electron beam evaporation, and laser ablation used for high temperature superconductors.

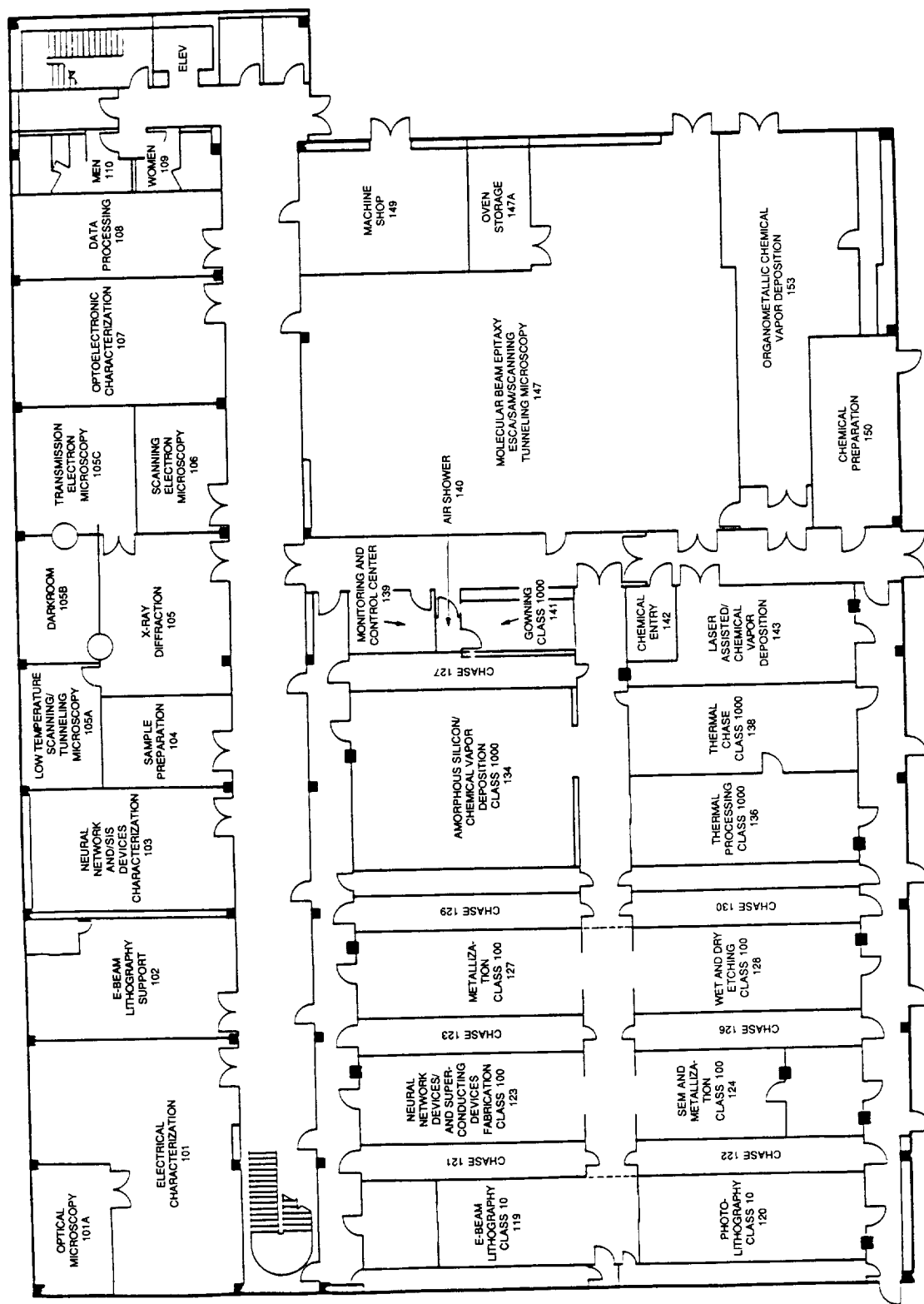
Devices are fabricated using optical and electron beam lithography, diffusion and oxidation, and wet and dry etching. The MDL houses a state-of-the-art Electron Beam Lithography Laboratory in a class 10 clean room. The JEOL JBX-5DII e-beam lithography system can focus its writing beam down to an 8 nanometer diameter. It is expected that 40 nanometer (0.04 micron) structures will be the working norm for patterns created with the JBX-5DII.

The Electron Beam Lithography Laboratory also has a complete array of support equipment. Included are a JEOL IC-848 scanning electron microscope with an image processing attachment, a Zeiss Axiophot optical microscope with TV monitor and image processing capability, a Leitz MPV-SP film thickness measurement tool, a surface particle contamination measurement instrument, an airborne particle count measurement tool, Soletec spinners for coating and developing photoresist, a YES vacuum priming oven, several baking ovens and both acid and solvent wet benches.

Materials and devices are characterized using state-of-the-art electrical and optoelectronic techniques. Surfaces and interfaces are studied using photoemission, scanning auger microscopy (SAM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), scanning tunneling microscopy (STM), and ballistic electron emission microscopy (BEEM).

## **Summary**

The JPL Microdevices Laboratory is fully operational including the state-of-the-art JEOL electron beam lithography system. This facility enables the end-to-end fabrication of devices down to submicron feature size based on silicon, amorphous silicon, compound semiconductors, and superconductors. The MDL also has full capability for surface/interface and bulk electrical and optical characterization of materials and devices.



MDL  
FIRST FLOOR





## Overview

The Solid State Device Research Program is directed toward developing innovative devices for space remote and in-situ sensing, and for data processing. Innovative devices can result from the "standard" structures in innovative materials such as superconductors, strained-layer superlattices, or even metalloproteins. Innovative devices can also result from "innovative" structures achieved using electron tunneling or nanolithography in standard materials. A final step is to use both innovative structures and innovative materials.

The Solid State Device Research effort is housed in the new Microdevices Laboratory which is described in the introduction to the section, *Microdevices Laboratory*.

## 1988-1989 Major Technical Achievements

### Electron Tunneling

- The new Ballistic Electron Emission Microscopy (BEEM) technique was **invented and developed** to enable many new capabilities for device structure diagnostics.
- BEEM **enabled** the first electron transport spectroscopy in semiconductor device structures which allows detailed characterization of the response of device components. Using BEEM, some of the most important material and interface factors limiting interface transport in devices were identified.
- BEEM methods were **developed** which enable direct measurement of subsurface interface band structure.
- BEEM was employed to identify defects in the important Au/GaAs Schottky barrier device structure. The origin of the defects was **identified** and the defects' dependence on device fabrication methods was determined.
- New device processing methods were **developed** which enabled all in-situ fabrication of metal/III-V Schottky device structures for the first time. The first ideal-interface Au/GaAs (100) Schottky barrier was fabricated using these methods.
- A prototype silicon micromachined tunnel position sensor was **designed, fabricated and successfully tested**. The tunnel accelerometer technology was **transferred** to the C.S. Draper Laboratory.

### Superconductivity

- **Designed** and built high vacuum sputter deposition facility to deposit qualifiable NbN/MgO/NbN Superconductor-Insulator-Superconductor (SIS) mixer elements. The superconducting refractory, space transition temperature is 16 K.
- **Fabricated** NbN/AlN/NbN tunnel junctions. MgO barriers are superior.
- **Designed and built** low-temperature scanning tunneling microscope. Major accomplishments include:

- **Observation** of superconductor-vacuum-normal metal tunneling at high resolution and high tunneling resistance.
- **First observation** of superconductor phonon density of states effects using STM.
- **First observation** of superconductor vacuum-superconductor tunneling using low-temperature scanning tunneling microscope.
- **Explored** small area tunnel junction geometries. Edge geometry tunnel junctions were fabricated with areas down to 0.1 square microns.
- **Fabricated** high-quality NbN edge junctions on thin quartz and delivered for receiver testing. These are the first NbN edge junctions to undergo receiver testing. Test results indicated greater than a factor of 3 improvement in performance over previous devices, with a noise temperature of ~380 K at 205 GHz.
- **Fabricated** an array of NbN junctions that demonstrated remarkably good lateral uniformity, with only a 3% spatial deviation (1 sigma) in the critical current density across a 6 mm distance. Such uniformity is important for future applications requiring arrays and circuits in the NbN system.
- **Transferred** NbN/MgO/NbN technology to an industrial collaborator (TRW) to fabricate superconducting A/D converters for IR sensor readout circuits.
- **Developed** a bromine-based chemical etch for high-temperature superconducting  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  films which removes the nonsuperconducting hydroxides and carbonates that form as a result of atmospheric exposure. This results in a stoichiometric, superconducting surface, which is important for future device applications of these thin films.
- **Developed** wet chemical techniques for passivation of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  against environmental degradation. Such techniques are critical for the avoidance of adverse effects on the performance of superconducting contacts, tunnel junctions, and other devices.
- **Fabricated and tested**  $\text{YBaCuO}/\text{Au}/\text{Nb}$  SNS device structures for electrical surface characterization of chemically-treated  $\text{YBaCuO}$  thin films. The tests indicated that high quality, superconducting surfaces can be obtained on  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ .

#### **Submillimeter (Terahertz) Receiver Technology**

- **Fabricated**  $\text{InGaAs}/\text{AlAs}$  quantum well resonant tunneling devices with a cutoff frequency near 1000 GHz. These devices are used as fundamental oscillators and frequency multipliers in submillimeter heterodyne receivers (1 mm = 300 GHz = 0.3 THz).
- **Demonstrated** frequency multiplication to 200 GHz.
- **Demonstrated** fundamental oscillation at 425 GHz.

- **Developed** first NbN/MgO/NbN edge junction.
- **Fabricated** edge and mesa junctions with integral tuning stubs.
- **Tested** edge and mesa junctions as mixers at 200 GHz performance within a factor of 4 of best Pb alloy results.
- **Developed** planar antenna configuration for dielectrically filled parabola.
- **Demonstrated** Barrier-Intrinsic-N type (BIN) diode concept for submillimeter wave GaAs multiplier grids. Demonstrated (with UCLA) a 1 Watt, 100 GHz output from BIN diode arrays.
- **Developed** theoretical model of novel far-infrared laser, based on intersubband transitions in GaAs/AlGaAs quantum wells, with current injection. The model predicts feasibility of submillimeter radiation generation at moderate threshold currents for the 60 - 150  $\mu\text{m}$  range.

### **Semiconducting Materials: Growth and Characterization**

- **Demonstrated** for the first time the growth of diamond-like carbon thin films by electron cyclotron resonance plasma deposition. This technology has application to high temperature devices and to advanced optical coatings for sensor protection in space.
- **Demonstrated** growth of high-quality GaAs/AlGaAs structures on Si substrates by a combination of migration enhanced molecular beam epitaxy (MEMBE) and MOCVD techniques.
- **Demonstrated** for the first time the planar oxide maskless growth of GaAs on Si substrates by migration-enhanced molecular beam epitaxy (MEMBE) followed by transient-mode liquid phase epitaxy (TMLPE) in collaboration with the University of Florida.
- **Demonstrated** the first successful growth of single-crystal, pinhole-free  $\text{CoSi}_2$  and  $\text{IrSi}_3$ . These materials are being used in ongoing work in Si-based Schottky-diode IR detectors.
- **Developed** a novel MOCVD process, enabling the first successful epitaxial growth of CdMgTe.
- **Demonstrated** growth of detector quality InAs thick films on GaAs (100) substrates.
- **Demonstrated** growth of InAs quantum wells strained to match the GaAs lattice constant. With new stoichiometry control techniques, obtained quantum well luminescence intensities up to 8 times greater than those for the bulk GaAs reference quantum wells for well thicknesses from 1 to 4 monolayers.

## Electronic Device Technology

- **Established** a state-of-the-art Electron Beam Lithography Laboratory, comprised of a JEOL JBX-5DII e-beam lithography system, JEOL IO-848 scanning electron microscope complete with image processing equipment, a Zeiss microscope, a Leitz film thickness measurement tool, PMS surface particle contamination and airborne particle count instruments, and related photoresist processing equipment, all housed in a Class 10 clean room bay of the Microdevices Laboratory. The JEOL JBX-5DII has greater resolution than any other commercially available e-beam lithography system, and is capable of generating a probe beam only 8 nanometers in diameter.
- **Made operational** the photodetachment atomic oxygen source. This is the only source in the world capable of delivering a pure, ground-state beam of atomic oxygen, with a variable energy in the range 2-50 eV, and a flux comparable to that encountered by spacecraft in low earth orbit.
- **Demonstrated** that an oxide layer could be formed on SiO<sub>2</sub> by room-temperature exposure to a low-energy O<sup>-</sup> beam. The O<sup>-</sup> beam is several orders of magnitude more reactive than a comparable beam of O<sub>2</sub>.
- **Fabricated** high-gain AlGaAs intrinsic-base and Zn-diffused extrinsic-base double heterojunction bipolar transistors (DHBTs) grown by MOCVD. Single transistors exhibited a current gain of 500-750 at a collector current density of 500 A/cm<sup>2</sup> and their Darlington transistor pairs showed current gains up to 5000.

## Molecular Electronics

- **Demonstrated** self-orientation of proteins relative to a surface by utilizing X-ray photoelectron spectroscopy (XPS) in conjunction with a novel myoglobin derivative.

## Electron Tunneling

### Publications

"Observations of Interface Bandstructure by Ballistic-Electron-Emission Microscopy"

L. D. Bell, W. J. Kaiser

Phys. Rev. Lett., 61, 2368 (1988)

"Spatially Resolved Ballistic Electron Spectroscopy of Subsurface Interfaces"

L. D. Bell, W. J. Kaiser

J. Microscopy 152, 605 (1988)

"Scanning Tunneling Microscopy Methods for Spectroscopic Imaging of Subsurface Interfaces"

L. D. Bell, W. J. Kaiser

Scanning Microscopy, 2, 1231 (1988)

"Process Dependent Morphology of the Si/SiO<sub>2</sub> Interface Measured with STM in SiO<sub>2</sub> and its Interfaces"

M. H. Hecht, L. D. Bell, F. J. Grunthaner, W. J. Kaiser

S. T. Pantelides and G. Lucovsky, eds., MRS proceedings, 105, 307 (1988)

"Superconducting Phonon Spectroscopy using a Low-Temperature Scanning Tunneling Microscope"

H. G. LeDuc, W. J. Kaiser, B. D. Hunt, L. D. Bell, R. C. Jaklevic, M. G. Youngquist  
Appl Phys. Lett., 54, 946 (1989)

"An Electron Tunneling Sensor"

S. B. Waltman, W. J. Kaiser

Sensors and Actuators, 19, 201 (1989)

"Electron Tunnel Sensor Technology"

S. B. Waltman, W. J. Kaiser

Journal of the British Interplanetary Society, 42, 474 (1989)

"Direct Investigation of Subsurface Interface Electronic Structure by Ballistic Electron Emission Microscopy"

W.J. Kaiser, L.D. Bell

Phys. Rev. Lett. 60, 1406 (1988)

"Ballistic-Electron-Emission Microscopy and Spectroscopy of Au-GaAs Interfaces"

W. J. Kaiser, L. D. Bell, M. H. Hecht, F. J. Grunthaner

J. Vac. Sci. Technol., B7, 945 (1989)

"Ballistic-Electron-Emission Microscopy and Spectroscopy of Au/GaAs Interfaces"

W.J. Kaiser, M.H. Hecht, L.D. Bell, F.J. Grunthaner

J. Vac. Sci. Technol. B7, 845 (1989)

"Ballistic-Electron-Emission Microscopy Investigation of Schottky Barrier Interface Formation"

M. H. Hecht, L. D. Bell, W. J. Kaiser, F. J. Grunthaner

App. Phys. Lett., 55, 780 (1989)

"Ballistic-Electron-Emission Microscopy Investigation of Schottky Barrier Interface Formation"

M.H. Hecht, L.D. Bell, W.J. Kaiser, F.J. Grunthaner  
Applied Physics Letters, 55, 780 (1989)

"Ballistic-Electron-Emission Microscopy of Subsurface Defects at the Au/GaAs (100) Interface"

M.H. Hecht, L.D. Bell, W.J. Kaiser  
Applied Surf. Sci. (accepted for publication)

## **Presentations**

"Imaging Subsurface Interfaces by Ballistic Electron Emission Microscopy"

L. D. Bell

*Invited* presentation at the Electrochemical Society Meeting, Chicago, October 10-14, 1988

"Direct Imaging of Subsurface Interface Properties by Ballistic Electron Emission Microscopy"

L. D. Bell, W. J. Kaiser

Scanning Tunneling Microscopy Conference, Oxford, UK, July 4-8, 1988

"Interface Imaging by BEEM"

L. D. Bell

*Invited* presentation at joint APS/AAPT Symposium on STM, San Francisco, CA, January, 14-19, 1989

"BEEM"

L. D. Bell

*Invited* presentation, STM '89, Oarai, Japan, July 10-14, 1989

"Ballistic Electron-Emission Microscopy: Scanning Tunneling Microscopy Applied to Subsurface Interfaces"

L.D. Bell

*Invited* presentation, Physics Department Seminar, Rensselaer Polytechnic Institute, NY, October, 1989

"Ballistic Electron-Emission Microscopy of Semiconductor Interface Structure"

L.D. Bell

*Invited* presentation, New York Chapter of the American Physical Society, Symposium on STM, October, 1989

"Ballistic-Electron-Emission Microscopy and Spectroscopy of Au-GaAs Interfaces"

L. D. Bell, M. H. Hecht, and W. J. Kaiser

*Invited* presentation at Physics and Chemistry of Semiconductor Interfaces Meeting, Bozeman, MT, February 7-9, 1989

"Ballistic Electron Emission Microscopy and Spectroscopy of Subsurface Interfaces"

L. D. Bell

*Invited* presentation, Cal. State Northridge, Northridge, CA, March 8, 1989

"Scanning Tunneling Microscopy Investigation of Semiconductor Surfaces and Interfaces"  
W.J. Kaiser  
*Invited* presentation, Solid State Sciences Seminar at Sandia National Laboratories,  
February 12, 1988

"Scanning Tunneling Microscopy Investigation of Semiconductor Interfaces"  
W.J. Kaiser  
*Invited* presentation, American Physical Society Meeting, April 21, 1988

"Scanning Tunneling Microscopy Investigation of Semiconductor Surfaces and Interfaces"  
W.J. Kaiser  
*Invited* presentation, Scanning Microscopy Meeting, May 2, 1988

"Subsurface Interface Imaging by Ballistic Electron Emission Microscopy"  
W.J. Kaiser  
*Invited* presentation, Naval Research Laboratory, August 29, 1988

"Spectroscopic Probing of Semiconductor Interface Structure with Nanometer Spatial Resolution"  
W. J. Kaiser  
*Invited* presentation at 2nd International Conference on the Formation of Semiconductor Interfaces (ICSFI), Osaka, Japan, November 8-12, 1988

"Spectroscopic Probing of Semiconductor Interface Structure with Nanometer Spatial Resolution"  
W. J. Kaiser  
*Invited* presentation, Applied Physics Seminar, California Institute of Technology, Pasadena, CA, November 15, 1988

"Subsurface Interface Imaging by Ballistic Electron Emission Microscopy"  
W. J. Kaiser  
*Invited* presentation at the Naval Research Laboratory, August 29, 1988

"Spectroscopic Probing of Subsurface Interface Properties with Nanometer-Scale Resolution"  
W. J. Kaiser  
*Invited* presentation at American Vacuum Society Meeting, Atlanta, GA, October 4, 1988.

"Spectroscopic Probing of Semiconductor Interface Structure with Nanometer Spatial Resolution"  
W. J. Kaiser  
*Invited* presentation, Applied Physics Seminar, California Institute of Technology, Pasadena, CA, November 15, 1988

"Ballistic Electron Emission Spectroscopy"  
W. J. Kaiser  
AVS Thin Film and Surface Science Open House, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, January 23, 1989

"Ballistic Electron Emission Spectroscopy"  
W. J. Kaiser  
*Invited* presentation, American Physical Society Meeting, St. Louis, MO, March 20-24, 1989

"BEEM: A Nanometer-Resolution Probe of Subsurface Interfaces"

W. J. Kaiser

*Invited* presentation, SEM 1989 Meeting, Long Beach, CA, April 7-9, 1989

"Ballistic-Electron-Emission Microscopy Investigation of Semiconductor Interfaces"

W. J. Kaiser, L. D. Bell, M. H. Hecht

*Invited* presentation, Semiconductor Sciences Seminar, IBM T. J. Watson Research Center, Yorktown Heights, NY, May 24, 1989

"Ballistic-Electron-Emission Microscopy Investigation of Semiconductor Interfaces"

W. J. Kaiser, L. D. Bell, M. H. Hecht

*Invited* presentation, Interface Science Seminar, National Institute of Standards and Technology, Gaithersburg, MD, May 25, 1989

"Scanning Tunneling Microscopy Investigation of Semiconductor Interfaces"

W.J. Kaiser

*Invited* presentation, International Vacuum Congress, Cologne, Germany, September, 1989

"Ballistic-Electron Emission Microscopy: Imaging and Spectroscopy of Subsurface Interfaces"

W.J. Kaiser

*Invited* presentation, IBM, Zurich Research Laboratory, October, 1989

"Ballistic-Electron Emission Microscopy: Imaging and Spectroscopy of Subsurface Interfaces"

W.J. Kaiser

*Invited* presentation, Physics Department Seminar, Cornell University, Ithaca, NY., November 21, 1989

"Semiconductor Interface Electronic Structure Investigation by Ballistic-Electron-Emission Microscopy"

W.J. Kaiser

*Invited* presentation, Materials Research Society Meeting, Boston, MA., November 27-December 2, 1989

"Electron Tunnel Sensors"

S. B. Waltman, W. J. Kaiser

Vacuum Microelectronics Conference, Williamsburg, VA, June 13-17, 1988

"Schottky Diode Characteristics, Surface Chemistry, and Surface Structure on Melt-Grown and MBE-Grown GaAs(100) Surfaces"

M. H. Hecht, L. D. Bell, F. J. Grunthaner, W. J. Kaiser

PCSI Meeting, Physics and Chemistry of Semiconductor Interfaces Meeting, Bozeman, MT, February 7-9, 1989

"Ballistic Electron Emission Microscopy of Au/GaAs Interfaces"

M. H. Hecht

*Invited* presentation, Colorado School of Mines, Golden, CO, February 6-9, 1989

"Ballistic-Electron Emission Microscopy Investigation of Semiconductor Interfaces"

M.H. Hecht

*Invited* presentation, International Conference on Electron, Ion, and Photon Beams, Monterey, CA, May, 1989



"Ballistic Emission Spectroscopy AlAs Quantum Structures"

M. H. Hecht

STM '89, Oarai, Japan, July 10-24, 1989

"Interface Chemistry and Electrical Characteristics of Au Schottky Diodes Formed In-situ on Melt-Grown and Molecular-Beam-Epitaxy-Grown GaAs (100) Surfaces"

M. H. Hecht, L. D. Bell, W. J. Kaiser, F. J. Grunthaner

American Physical Society Meeting, St. Louis, MO, March 20-24, 1989

"Ballistic-Electron-Emission Microscopy Investigation of Semiconductor Interfaces"

M. H. Hecht

*Invited* presentation, 33rd Symposium on Electron, Ion and Photon Beams, Monterey, CA, May 30-June 2, 1989

"The Observation of Superconductor-Superconductor Tunneling Using a Low-Temperature Scanning Tunneling Microscope"

H. G. LeDuc, W. J. Kaiser, L. D. Bell

American Physical Society Meeting, St. Louis, MO, March 20-24, 1989

### **Patents and New Technology Reports**

"Ballistic Electron Emission Microscope (BEEM)"

W. J. Kaiser, L. D. Bell

NASA Tech Brief NPO-17384

U. S. Patent No. 4,823,004

"Tunnel Effect Displacement Sensor"

W.J. Kaiser, S.B. Waltman

NASA Tech Brief NPO-17362

"Epitaxial Diffusion Barriers for Schottky Barrier Formation and Interdiffusion Control on Epitaxial Gallium Arsenide Films"

W.J. Kaiser, F.J. Grunthaner, L.D. Bell, M.H. Hecht

NPO-17796

"Formation of Room Temperature Ohmic Contacts on Epitaxial Gallium Arsenide Films"

L.D. Bell, M.H. Hecht, W.J. Kaiser

NPO-17795

## Superconductivity

### Publications

"NbN/MgO/NbN SIS Tunnel Junctions for Submm Wave Mixers"

J. A. Stern, B. D. Hunt, H. G. LeDuc, A. Judas, W. R. McGrath, S. R. Cypher, S. K. Khanna

IEEE Trans. Magn., 25, 1054 (1989)

"NbN/MgO/NbN Edge-Geometry Tunnel Junctions"

B. D. Hunt, H. G. LeDuc, S. R. Cypher, J. A. Stern, A. Judas

App. Phys. Lett., 55, 1801 (1989)

"Superconducting Phonon Spectroscopy Using a Low-Temperature Scanning Tunneling Microscope"

H.G. LeDuc, W.J. Kaiser, B.D. Hunt, L.D. Bell, R.C. Jaklevic, M.G. Youngquist

Applied Physics Letters (submitted)

"Y-Ba-Cu-O Superconducting Thin Films by Simultaneous or Sequential Evaporation"

A. Mogro-Campero, B. D. Hunt, L. G. Turner, M. Burrell, W. E. Balz

Appl. Phys. Lett. 52, 584 (1988)

"Superconducting Y-Ba-Cu-O Films by Evaporation"

A. Mogro-Campero, B. D. Hunt, L. G. Turner, M. C. Burrell, W. E. Balz

Mat. Res. Soc. Proc., EA-14 (1988)

"A Nonaqueous Chemical Etch for YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub>"

R. P. Vasquez, B. D. Hunt, M. C. Foote

Appl. Phys. Lett., 53, 2692 (1988)

"A Nonaqueous Chemical Etch for YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub>"

R. P. Vasquez, B. D. Hunt, M. C. Foote

Proceedings of the AVS Topical Conference on Superconducting Thin Films, Devices, and Characterization; October 3, 1988, Atlanta, Georgia, AIP Conference Proceedings #182, p 376

"Nonaqueous Chemical Depth Profiling of YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub>"

R. P. Vasquez, M. C. Foote, B. D. Hunt

App. Phys. Lett., 54, 1060 (1989)

"Reduced Reactivity to Air on HF-treated YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> Surfaces"

R. P. Vasquez, B. D. Hunt, M. C. Foote

App. Phys. Lett., 54, 2273 (1989)

"Wet Chemical Etching Techniques for Passivation of YBaCuO"

R. P. Vasquez, M. C. Foote, B. D. Hunt

App. Phys. Lett., 55, 1801 (1989)

"Wet Chemical Techniques for Passivation of YBaCuO"

R. P. Vasquez, M.C. Foote, B.D. Hunt

Proceedings of the American Vacuum Society Conference, Boston, MA, October 23, 1989

"Wet Chemical Passivation of YBaCuO"  
R.P. Vasquez, B.D. Hunt, M.C. Foote  
J. Electrochem. Soc., December 5, 1989

"Electrical Contact Studies of Chemically Treated YBaCuO Surfaces"  
B.D. Hunt, M.C. Foote, R.P. Vasquez  
American Vacuum Society Conference Proceedings, Boston, MA, October 23, 1989

"XPS Core Level Spectra of Some Y Compounds"  
R. P. Vasquez  
Journal of Electron Spectroscopy (accepted for publication)

"Reaction of Nonaqueous Halogen Solutions with YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>"  
M.C. Foote, B.D. Hunt  
Journal of Applied Physics, November, 1989

"Growth and Characterization of Large YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> Single Crystals"  
K.L. Keester, R.M. Housely, D.B. Marshall  
J. Crystal Growth 91, 295 (1988)

"Syntactic Intergrowth Problems with BCSCO and Fabrication Difficulties Therefrom"  
P.E.D. Morgan, J.J. Ratto, R.M. Housely, J.R. Porter  
Better Ceramics Through Chemistry III, MRS Symposium Proceedings, Vol. 121 (1988)  
eds., C.J. Brinker, D.E. Clark, D.R. Ulrich, p. 421

"Synthesis Variability and Syntactic Intergrowths in the BCSCO System:  
J.J. Ratto, R.M. Housely, J.R. Porter, P.E.D. Morgan  
Ceramic Superconductors II, Am. Ceram. Soc. (1988) ed., M.R. Yan, p. 177

"Ceramic Problems/Challenges in High Temperature Oxide Superconductors, Hysteretic  
Force Measurements as a New Analysis Tool"  
P.E.D. Morgan, J.J. Ratto, R.M. Housely, J.R. Porter, D.B. Marshall, R.E. DeWames  
International Superconductivity Symposium, Nagoya, Japan, August, 1988

"Low Activation Energy Damage in Ion Bombarded YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> Thin Films"  
I.S. Gergis, P.H. Kobrin, J.F. DeNatale, R.M. Housely  
Rockwell Science Center, Thousand Oaks, CA  
Proceedings of the Conference on Unusual Superconducting Mechanisms, Stanford, 1989

## **Presentations**

"NbN/MgO/NbN SIS Tunnel Junction for Submm Wave Mixers"  
J. A. Stern, B. D. Hunt, H. G. LeDuc, A. Judas, W. R. McGrath, S. R. Cypher, S.K.  
Khanna  
Applied Superconductivity Conference, San Francisco, CA, August 21-25, 1988

"Superconducting Devices"  
H. G. LeDuc  
AVS Thin Film and Surface Science Open House, Jet Propulsion Laboratory, California  
Institute of Technology, Pasadena, CA, January 23, 1989

"Investigation of High  $T_c$  Superconducting Thin Films for Device Applications"  
B. D. Hunt, M. C. Foote, R. P. Vasquez, H. G. LeDuc, D. M. Stayer  
DARPA High Temperature Superconductor Conference, Washington, D.C., September 13, 1988

"NbN/MgO/NbN Edge Junctions"  
B. D. Hunt, H. G. LeDuc, S. R. Cypher  
American Physical Society Meeting, St. Louis, MO, March 20-24, 1989

"Electrical Characterization of Chemically-Modified  $YBa_2Cu_3O_{7-x}$ "  
B. D. Hunt, M. C. Foote, R. P. Vasquez, H. G. LeDuc, W. J. Kaiser  
Materials Research Society Meeting, San Diego, April 24-28, 1989

"NbN/MgO/NbN Edge Junction: Fabrication and SIS Mixer Results"  
B.D. Hunt, H.D. LeDuc, S.R. Cyper, A. Judas, W.R. McGrath, C.N. Byron  
*Invited* presentation, Superconductive Electronics Workshop, St. Michael's MD, October 2, 1989

"Electrical Contact Studies of Chemically Treated  $YBa_2Cu_3O_{7-x}$  Surfaces"  
B. D. Hunt, M. C. Foote, R. P. Vasquez  
American Vacuum Society Topical Conference on High  $T_c$  Superconducting Thin Films: Processing, Characterization and Applications, Boston, MA, October 23, 1989

"NbN Edge Junctions and Electrical Characterization of Chemically Modified  $YBaCuO$  Thin Film Surfaces"  
B.D. Hunt  
*Invited* presentation, IBM T.J. Watson Research Center, Yorktown Heights, NY, August 8, 1989

"High-Temperature Superconductor Thin Film Devices"  
B. D. Hunt  
NASA Program Review of High-temperature Superconductor Work Within NASA, Goddard Space Flight Center, Greenbelt, MD, August 29, 1989

"Exploratory Study in Making As-Deposited  $YBa_2Cu_3O_{7-\delta}$  Films Using a  $BaF_2$  Source"  
M. C. Foote, B. D. Hunt, R. Livi, P. Haubert, M. Dobeli, T. A. Tombrello, D. L. Goodstein  
SEM 1989 Meeting, Long Beach, CA, April 5-7, 1989

"Surface Characterization of As-Deposited, Post-Annealed, and Chemically Modified  $YBa_2Cu_3O_{7-\delta}$  Films"  
M. C. Foote, B. D. Hunt, R. P. Vasquez  
American Physical Society Meeting, St. Louis, MO, March 20-24, 1989

"A Nonaqueous Chemical Etch for  $YBaCu$ "  
R. P. Vasquez, B. D. Hunt, M. C. Foote  
American Vacuum Society Meeting, New Orleans, LA, October 3, 1988

"Reactions of Nonaqueous Halogen Solutions with  $YBa_2Cu_3O_{7-x}$ "  
R. P. Vasquez, M. C. Foote, B. D. Hunt  
Materials Research Society Meeting, San Diego, CA, April 24-28, 1989

"Wet Chemical Techniques for Passivation of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ "

R. P. Vasquez, B. D. Hunt, M. C. Foote

American Vacuum Society Topical Conference on High  $T_c$  Superconducting Thin Films: Processing, Characterization and Applications, Boston, MA, October 23, 1989

"Evolution of Layered High Temperature Superconducting Oxide Precursor Films Under High Energy Heavy Ion Bombardment"

M.C. Foote, R.D. Hunt, R. Livi, P. Haubert, M. Dobeli, T.A. Tombrello, R.M. Housely, D.L. Goodstein

Scanning 89/EM West Conference, Long Beach, CA, 1989

"New Approaches to Monitoring the Preparation and Properties of High  $T_c$  Superconductors"

J.J. Ratto, P.E.D. Morgan, R.M. Housely, J.R. Porter, D.B. Marshall, R.E. DeWames  
MRS Spring Conference, San Diego, CA, 1989

"Monitoring Sintering/Densification and Crystallization/Grain Growth in Tl-Based High Temperature Superconductors by Electrical Resistance Measurements"

J.J. Ratto, J.R. Porter, R.M. Housely, P.E.D. Morgan  
MRS Fall Conference, Boston, MA, 1989

"Scanning Electron Microscope and Heavy Ion RBS Characterization of Thin Bi-Sr-Ca-Cu-O Films"

R.M. Housely, P. Kobrin, A. Harker, P. Haubert, M. Dobeli, R. Livi, D.L. Goodstein, T. Tombrello

Scanning 89/EM West Conference, Long Beach, CA, 1989

"Critical Currents in Highly Oriented Melt Deposited Films of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ "

R.M. Housely, P.E.D. Morgan, J.J. Ratto, I.B. Goldberg  
Rockwell International Science Center, Thousand Oaks, CA  
MRS Spring Conference, 1990 (submitted)

## **Patents and New Technology Reports**

"Surface Halogenation of High-Temperature Superconductors"

R. P. Vasquez

NASA Tech Brief NPO-17712

"Long Wavelength Infrared Detector"

R.P. Vasquez

NASA Tech Brief NPO-17543 (patent pending)

"Oxidation of Semiconductors and Superconductors"

R.P. Vasquez

NASA Tech Brief NPO-17534 (patent pending)

## Submillimeter (Terahertz) Receiver Technology

### Publications

"NbN/MgO/NbN SIS Tunnel Junctions for Submm Wave Mixers"

J. A. Stern, B. D. Hunt, H. G. LeDuc, A. Judas, W. R. McGrath, S. R. Cypher, S. K. Khanna

IEEE Trans. Magn., 25, 1054 (1989)

"Fundamental Oscillations Up to 200 GHz in Resonant Tunneling Diodes and New Estimates of Their Maximum Oscillation Frequency from Stationary-State Tunneling Theory"

E. R. Brown, W. D. Goodhue, T. C. L. G. Sollner

J. Appl. Phys. 64, p. 1519 (1988)

"Harmonic Multiplication Using Resonant Tunneling"

T. C. L. G. Sollner, E. R. Brown, W. D. Goodhue, C. A. Correa

J. Appl. Phys. 64, p. 4248 (1988)

"Microwave and Millimeter-Wave Resonant-Tunneling Devices"

T. C. L. G. Sollner, E. R. Brown, H. Q. Le

Lincoln Lab. J., 1, p. 89 (1988)

"Effects of Quasibound-states Lifetime on the Oscillation Power of Resonant Tunneling Diodes"

E. R. Brown, C. D. Parker, T. C. L. G. Sollner

Applied Physics Letters, 54, p. 934 (1989)

"Experimental Results of a High Q Quasioptical Reflection Cavity"

K. A. Lee, M.A. Frerking

Int'l. J. IR & MMWaves, 10, 789 (1989)

"The Dielectric-Filled Parabola: A New Millimeter/Submillimeter Wavelength Receiver/Transmitter Front End"

P. H. Siegel

IEEE Trans. Ant. & Prop. (1989)

"Measurements of Dipole, Bow-Tie, Log-Periodic and Log-Spiral Antennas on a Dielectric-Filled Parabola"

P. H. Siegel

IEEE Trans. Ant. & Prop. (1989)

"Oscillations up to 420 GHz in GaAs/AlAs Resonant-Tunneling Diodes"

E. R. Brown, T. C. L. G. Sollner, C. D. Parker, W. D. Goodhue, C. L. Chen

Applied Physics Letters, 55, p. 1777 (1989)

"Evaluation of the Feasibility of a Far Infrared Laser Based on Intersubband Transitions in GaAs Quantum Wells"

S. Borenstain, J. Katz

Applied Physics Letters 55, 654 (1989)

## **Presentations**

### **"Quantum Well Multipliers"**

P. D. Batelaan, M. A. Frerking

Proceedings of the Twelfth International Conference on Infrared and Millimeter Waves, p. 14 (1987)

### **"A Quantum-Well Frequency Multiplier with Millimeter-Wave Output"**

P. D. Batelaan, M. A. Frerking

Proceedings of the Fourth International Conference on Infrared Physics, p. 527 (1988)

### **"Theoretical Performance of Quantum Well Multipliers"**

M.A. Frerking

Solid State THz Sources Workshop, Pasadena, CA, August 1988

### **"A Novel Noncontacting Waveguide Backshort Design for Millimeter and Submillimeter Wave Frequencies"**

W. R. McGrath

IEEE MTT-S International Microwave Symposium, Dallas, TX (1990) (submitted)

### **"205 GHz SIS Receiver Development"**

W. R. McGrath, C. N. Byrom, B. N. Ellison, M. A. Frerking, H. G. Leduc, R. E. Miller, J. A. Stern

Digest Int. Symp. Submm & mm Astron., Kona, HI, 3--6 October, 1988

### **"205 GHz SIS Receiver Development for Remote Sensing Applications"**

W. R. McGrath, C. N. Byrom, B. N. Ellison, M. A. Frerking, R. E. Miller

Digest of the 13th International Conference on Infrared and Millimeter Waves, (R. J. Temkin, ed.), p. 98 (1988). Published by the International Society for Optical Engineering, Bellingham, Washington

### **"Large Scale Modeling of a Submillimeter Wave SIS Mixer with Integrated Tuning Elements"**

K. Jacobs, W. R. McGrath

Digest of the 14th International Conference on Infrared and Millimeter Waves (M. von Ortenberg, ed.), p. 539, Wurzburg, Germany (1989)

### **"A Novel Noncontacting Waveguide Backshort Design for Millimeter and Submillimeter Wave Frequencies"**

W. R. McGrath

IEEE MTT-S International Microwave Symposium, Dallas, TX (1990) (submitted)

### **"Measurements of Dipole, Bow-tie, Log-Periodic and Log-Spiral Antennas on a Dielectric-Filled Parabola"**

P. H. Siegel, R. J. Dengler

1989 IEEE-AP-S International Symposium, vol. I., Antennas and Propagation (R. J. Pogorzelski, ed.), p. 94, San Jose, CA (1989)

### **"The Dielectric-Filled Parabola: A New High Frequency Integrated Receiver or Transmitter Front End"**

P. H. Siegel, M. A. Frerking

1989 IEEE-AP-S International Symposium, vol. III, Antennas and Propagation (R. J. Pogorzelski, ed.), p. 1191, San Jose, CA (1989)

"A Technique for Fabricating Free Standing Electrically Thick Metallic Mesh and Parallel Wire Grids for Use as Submillimeter Wavelength Filters and Polarizers"

P. H. Siegel, J. A. Lichtenberger

IEEE MTT Symposium (October, 1989)

"B-I-N Diodes"

U. Lieneweg

Presented at Solid State THz Sources Workshop, Pasadena, CA, August, 1988

### **Patents and New Technology Reports**

"Millimeter and Submillimeter Wave Quantum Well Frequency Multipliers"

P.D. Batelaan, M.A. Frerking

NASA Tech Brief NPO-17584

"Planar Antennas on Thick Dielectrics Substrates"

K. A. Lee, M.A. Frerking

NASA Tech Brief NPO-17466

"High Q Quasi-Optical Tunable Resonator"

K.A. Lee, M.A. Frerking

NPO-17919 (patent pending)

"A New Noncontacting Waveguide Backshort Design Employing a Novel Geometry"

W. R. McGrath

NPO-18091

"Dielectric Filled Parabola With Integrated Planar Antenna for Use as a Millimeter/Submillimeter Wavelength Receiver/Transmitter Front End"

P. H. Siegel

NPO-17802

"A Technique for Fabricating Electrically Thick Free Standing Metallic Mesh for Use at Submillimeter Wavelengths"

P. H. Siegel, J. A. Lichtenberger

NPO-17992

"Self-Operating Range Charger for Computer Interfacing the HP415E SWR Meter"

R. J. Dengler, P. H. Siegel

NPO-17822

"Infrared Multiquantum Well Phototransistor"

S. Borenstain

NPO-17980



# Semiconducting Materials: Growth and Characterization

## Publications

- "Growth of Single-Crystal Columns of  $\text{CoSi}_2$  Embedded in Epitaxial Si on Si (111)"  
R.W. Fathauer, C.W. Nieh, Q.F. Xiao, S. Hashimoto  
Applied Physics Letters 55, 247 (1989)
- "Heavily Boron-Doped Si Layers Grown Below 700 °C by Molecular Beam Epitaxy"  
T.L. Lin, R.W. Fathauer, P.J. Grunthaner  
Applied Physics Letters 55, 795 (1989)
- "Characterization of Si/ $\text{CoSi}_2$ /Si (111) Heterostructures Using Auger Plasmon Losses"  
F.D. Schowengerdt, L.T. Lin, R.W. Fathauer, P.J. Grunthaner  
Journal of Applied Physics 65, 3531 (1989)
- "Diffusion of Si on Thin  $\text{CoSi}_2$  Layers"  
F.D. Schowengerdt, L.T. Lin, R.W. Fathauer, P.J. Grunthaner  
Applied Physics Letters 54, 1314 (1989)
- "Growth of Epitaxial  $\text{CoSi}_2$ /Si Multilayers"  
B. D. Hunt  
In Properties of Silicon, Inspec, New York, 1988, p 1001
- "Growth of Si/ $\text{CoSi}_2$ /Si Heterostructures"  
B. D. Hunt  
Properties of Silicon, Inspec, New York, 1988, p 1039
- "Optical Properties of Epitaxial  $\text{CoSi}_2$  and  $\text{NiSi}_2$  Films on Silicon"  
J. R. Jimenez, Z. C. Wu, L. J. Schowalter, B. D. Hunt, R. W. Fathauer, P. J. Grunthaner, and T. L. Lin  
J. App. Phys., 66, 2738 (1989)
- "Structural Properties of Epitaxial  $\text{NiSi}_2$  on Si(111) Investigated with X-ray Standing Waves"  
J. Zegenhegen, K. G. Huang, W. M. Gibson, B. D. Hunt, And L. J. Schowalter  
Phys. Rev. B, 39, 10254 (1989)
- "Novel Photovoltaic  $\delta$ -doped GaAs Superlattice Structure"  
A.M. Glass, E.F. Schubert, B.A. Wilson, C.E. Bonner, J.E. Cunningham, D.H. Olson, W. Jan  
Applied Physics Letters 54, 2247 (1989)
- "Historical Perspective on Tunneling in  $\text{SiO}_2$ "  
J.Maserjian  
Physics and Chemistry of SiO and the Si-SiO<sub>2</sub> Interface, B. Deal Ed., Plenum Press, 1989
- "Transient-Mode Liquid Phase Epitaxial Growth of GaAs on GaAs-Coated Si Substrates Prepared by Migration-Enhanced Molecular Beam Epitaxy"  
S. Nakamura, S.Sakai, S.S. Chang, R.V. Ramaswamy, J.H. Kim, G. Radhakrishnan, J.K. Liu, and J.Katz  
Journal of Crystal Growth 97, 303 (1989)

"High Efficiency CdTe Thin-film Solar Cells Using Metalorganic Chemical Vapor Deposition Techniques"

A. Nouhi, R.J. Stirn

Journal of Vacuum Science Technology A 7(3), 833 (1989)

" $\Gamma$  to X Transport of Photoexcited Electrons in Type II GaAs/AlAs Multiple Quantum Well Structures"

P. Saeta, B.I. Green, R. Fischer, R.C. Spitzer and B.A. Wilson

Applied Physics Letters 54, 1681 (1989)

"Growth and Characterization of Single Crystal Insulators on Silicon"

L.J. Schowalter, R.W. Fathauer

CRC Critical Reviews in Solid State and Materials Sciences Vol. 15, 367-421 (1989)

"Radiative Recombination Mechanisms in Staggered-Alignment (GaAs)/(AlAs) Heterostructures"

B.A. Wilson, C.E. Bonner, R.C. Spitzer, R. Fischer, P. Dawson, K.J. Moore, and C.T. Foxon

Physical Review B 40, 1825 (1989)

"Novel Applications of Optical Techniques to the Study of Buried Semiconductor Interfaces"

B.A. Wilson

*Invited paper*, IEEE Journal of Quantum Electronics, Special Edition on Laser Diagnostics of Semiconductors, Vol. 25, 1012 (1989)

"Temperature Control and Calibration Issues in the Growth, Processing and Characterization of Electronic Material"

B.A. Wilson

Proceedings of the NASA Workshop on Non-Contact Thermal Measurement, Pasadena, CA, January 17-19, 1989

"Oxidation of Silicon with a 5 eV  $O^-$  Beam"

M. H. Hecht, O. J. Orient, A. Chutjian, R. P. Vasquez

Appl. Phys. Lett. 54, 421 (1989)

"Growth and Characterization of GaAs on Si Substrates by Migration-enhanced Molecular Beam Epitaxy"

J.H. Kim, J.K. Liu, G. Radhakrishnan, J. Katz, S. Sakai, S.S. Chang, N.A. El-Masry

Applied Physics Letters, 53, 2435 (1988)

"Characteristics of Annealed p/n Junctions between GaAs and Si (100)"

H. Morkoc, G. Radhakrishnan, J. Katz, et. al.

Applied Physics Letters (1988)

"Molecular Beam Epitaxy and Metalorganic Chemical Vapor Deposition Growth of Epitaxial CdTe on (100) GaAs/Si and (111) GaAs/Si Substrates"

A.Nouhi, G.Radhakrishnan, J. Katz, K. Koliwad

Applied Physics Letters 53, 2028 (1988)

"Laser-Assisted Molecular Beam Epitaxial Growth of GaAs on Si (100)"  
S. Guha, F. J. Grunthaner, A. Madhukar, J. K. Liu, P. D. Lao, W. C. Tang, P. Andersson, J. Iannelli, B. Pate  
Journal of Applied Physics 65 (1989)

"Extended Fine Structure Analysis of the Electron Energy Loss Spectrum of InAs/GaAs Strained Layer Quantum Wells"  
F. D. Schowengerdt, F. J. Grunthaner  
1988 Fall National Meeting of the Materials Research Society, Boston, MA, November 28-December 2, 1988; to appear in Mat. Res. Soc. Symp. Proc.

"Migration-Enhanced Molecular Beam Epitaxial Growth and Characterization of GaAs on Si Substrates"  
J.H. Kim, S. Sakai, J.K. Liu, G. Radhakrishnan, S.S. Chang, J. Katz  
MRS Proceedings, Vol. 144, paper W-4.3 (1988)

## **Presentations**

"Production of Epitaxial Columns of CoSi<sub>2</sub> in a Single-Crystal Silicon Matrix Using MBE"  
R.W. Fathauer, C.W. Nieh, Q.F. Xiao, S. Hashimoto  
European MRS, Strasbourg, France, May 30-June 2, 1989

"Topics in Molecular Beam Epitaxy of Metal Silicides"  
R.W. Fathauer  
*Invited* presentation, Philips Research Laboratory, Eindhoven, The Netherlands, June 12, 1989

"Topics in Molecular Beam Epitaxy of Metal Silicides"  
R.W. Fathauer  
*Invited* presentation, Swiss Federal Institute of Technology, Zurich, Switzerland, June 5, 1989

"Reduction of the Effective Barrier Height in Epitaxial CoSi<sub>2</sub>/Si (111) Diodes by Selective Doping from an HBO<sub>2</sub> Source"  
R.W. Fathauer, T.L. Lin, J.M. Iannelli, P.J. Grunthaner, J. Maserjian  
Fall MRS Meeting, Boston, MA, December, 1989

"Growth of CdTe Thin Films on Polar and Non-Polar Semiconductor Substrates by Metalorganic Chemical Vapor Deposition"  
P. Grodzinski, J.H. Mazur, A. Nouhi, R.J. Stirn  
MRS Fall Meeting, Boston, MA, November 28, 1989

"Ion Channeling Studies of Single-Crystal Columns of CoSi<sub>2</sub> Embedded in Epitaxial Si on Si (111) Grown by MBE"  
S. Hashimoto, Q.F. Xiao, W.M. Gibson, C.W. Nieh, R.W. Fathauer  
International Conference on Ion Beam Analysis, Kingston, Ontario, Canada, June 26-30, 1989

"Optical Properties and Electron Transport Across Interfaces in CoSi<sub>2</sub>/Si and NiSi<sub>2</sub>/Si"  
J.R. Jimenez, J.J. Schowalter, Z.C. Wu, B.D. Hunt, R.W. Fathauer, P.J. Grunthaner, T.L. Lin  
APS Meeting, St. Louis, March, 1989

"Growth of Iridium Silicide by MBE"

T.L. Lin, C.W. Nieh (Caltech), S. Hashimoto

European MRS, Strasbourg, France, May 30-June 2, 1989

"Growth of Heavily Boron-Doped Oxygen-Free Silicon Layers by MBE Using a Metabolic Acid Source"

T.L. Lin, R.W. Fathauer, P.J. Grunthaner

European MRS, Strasbourg, France, May 30-June 2, 1989

"MBE Growth of Iridium Silicide"

T.L. Lin

*Invited* presentation, Swiss Federal Institute of Technology, Zurich, Switzerland, June 5, 1989

"Electron-Induced Epitaxial Growth of  $\text{CoSi}_2$  on (111) Si"

C.W. Nieh, T.L. Lin, and R.W. Fathauer

1989 MRS Spring Meeting, San Diego, CA, April 24-28, 1989

"Interlayer Transport of Photoexcited Electrons in Type II GaAs/AlAs Multiple Quantum Well Structures"

P.Saeta, R.J. Fischer, B.I. Greene, R.C. Spitzer, B.A. Wilson

CLEO/QELS Meeting, Baltimore, MD, April 24-28, 1989

"Si Diffusion in MBE-Grown  $\text{CoSi}_2/\text{Si}$  (111) Heterostructures"

F.D. Schowengardt, T.L. Lin, R. W. Fathauer, P.J. Grunthaner

March, APS Meeting, St. Louis, MO, March, 1989.

"Long-Lived Metastable States in Novel GaAs Heterostructures"

R.C. Spitzer, B.A. Wilson, C.E. Bonner, L. Pfeiffer, A. M. Glass

CLEO/QELS Meeting, Baltimore, MD, April 24-28, 1989

"Electro-Optical Properties of GaAs/AlGaAs/AlAs/AlGaAs Staggered Alignment Heterostructures"

R.C. Spitzer, B.A. Wilson, C.E. Bonner, A.M. Glass

March, APS Meeting, St. Louis, MO, March, 1989

"Temperature Control and Calibration Issues in the Growth, Processing and Characterization of Electronic Materials"

B.A. Wilson

NASA Workshop on Non-Contact Thermal Measurement, Pasadena, CA, January 17-19, 1989

"Electro-Optical Properties of Staggered-Alignment AlGaAs Heterostructures"

B.A. Wilson

*Invited* presentation, CLEO/QELS Meeting, Baltimore, MD, April 24-28, 1989

"Optoelectronic Properties of Staggered-Alignment AlGaAs Heterostructures"

B.A. Wilson, R.C. Spitzer, C.E. Bonner, L. Pfeiffer

March, APS Meeting, St. Louis, MO, March, 1989

"Novel Applications of Optics: The Determination of Structural and Electronic Properties of Buried Semiconductor Interfaces"

B.A. Wilson

*Invited* presentation, Ontario Laser and Lightwave Research Center, University of Toronto, Canada, February 28, 1989

"Novel Applications of Optics: The Determination of Electronic and Structural Properties of Buried Semiconductor Interfaces"

B.A. Wilson

*Invited* presentation, SPIE Symposium on Raman Scattering, Luminescence and Spectroscopic Instrumentation on Technology, Los Angeles, CA, January 14-19, 1989

"Oxidation of Silicon with 5 eV O<sup>-</sup> Beam"

M. H. Hecht, O. J. Orient, A. Chutjian, R. P. Vasquez

IEEE Semiconductor Interface Specialists Conference, San Diego, CA, December 7-10, 1988

"Applied Surface and Interface Analysis"

M. H. Hecht

AVS Thin Film and Surface Science Open House, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, January 23, 1989

"Epitaxial Growth Experiments of (100) GaAs/Si and (111) GaAs/Si Using Molecular Beam Epitaxy and Metalorganic Chemical Vapor Deposition"

G. Radhakrishnan, A. Nouhi, J. Liu

SPIE OE/LASE '88, Los Angeles, January 11-15, 1988

"Heteroepitaxy of CdTe on GaAs-on-Si"

G. Radhakrishnan, A.M. Nouhi, J. Katz

Conference on Heterostructures on Si: One Step Further with Si, Cargese, Corsica, May 6-10, 1988

"Extended Fine Structure Analysis of the Electron Energy Loss Spectrum of InAs/GaAs Strained Layer Quantum Wells"

F. D. Schowengerdt, F. J. Grunthaner

1988 Fall National Meeting of the Materials Research Society, Boston, MA, November 28-December 2, 1988

"AES Analysis and RHEED Control of Growth Front Morphology in InAs Strained Layer Epitaxy"

F. J. Grunthaner, F. D. Schowengerdt\*, J. M. Iannelli, B. R. Hancock, J. K. Liu

Spring '89 MRS Meeting in April, 1989

\*Colorado School of Mines, Golden, Colorado

"Time-Resolved RHEED Analysis of Growth Front Morphology and Initial MBE Film Nucleation of GaAs on Si (100) and (111) Surfaces."

F. J. Grunthaner, J. M. Iannelli, B. R. Hancock, J. K. Liu

Spring '89 MRS Meeting in April, 1989

"Interface Morphology and Growth Front Stoichiometry in InAs/GaAs Strained Layer Epitaxy"

F. J. Grunthaner, J. K. Liu, J. M. Iannelli, B. R. Hancock, F. D. Schowengerdt\*  
4th International Conference on Modulated and Metastable Semiconductors (MSS) in July 1989 in Ann Arbor, MI

\*Colorado School of Mines, Golden, Colorado

"Interface Physics and Epitaxial Synthesis of Multilayer Materials"

F. J. Grunthaner

*Invited* presentation, 1988-89 AVS/CSMT Open House and Technical Workshop at JPL: Device Physics, Epitaxy and Interface Science, January 23, 1989

"RHEED as a Probe of Strained-Layer Synthesis and Crystallography"

F. J. Grunthaner

*Invited* presentation, Space Epitaxy Research Center Colloquium, University of Houston, Houston, Texas, January 26, 1989

"Critical Thickness and Dislocation Generation in InAs Strained-Layer Quantum Wells Grown on GaAs (100) Substrates"

F. J. Grunthaner, F. D. Schowengerdt, J. K. Liu, B. R. Hancock, J. M. Iannelli, P. Andersson

Physics of Compound Semiconductor Interfaces Conference (PCSI-16) Bozeman, Montana, February 7-10, 1989

"Stoichiometric Interface Control and Strained-Layer Epitaxy"

F. J. Grunthaner

*Invited* seminar, Distinguished Lecturer Series, Columbia University, NY, April 5, 1989

"III-V Strained-layer Synthesis and Novel Metastable Materials"

F. J. Grunthaner

*Invited* presentation, IBM T.J. Watson Research Center, Yorktown Heights, NY, April 6, 1989

"New Perspectives in Nanometer Control of Electronic Material Synthesis for Low-Dimensional Devices"

F. J. Grunthaner

*Invited* presentation, QUEST Colloquium on Future Device Opportunities, University of California at Santa Barbara, Santa Barbara, CA, August 26, 1989

Chemical And Electronic Structure of the SiO<sub>2</sub>/Si Interface and the Electrically Active Defects"

F. J. Grunthaner, P. J. Grunthaner

*Invited* presentation, Third International Conference on Passivation, Hokkido University, Sapporo, Japan, September, 1989

## **Patents and New Technology Reports**

"Hydrogen Stabilized Semiconductor Devices"

A.W. Overhauser, J. Maserjian

NASA Tech Brief NPO-17187 (patent pending)

"Oxidation of Semiconductors and Superconductors"

R. P. Vasquez

NASA Tech Brief NPO-17534 (patent pending)

"Variable-Energy Ion Beams for Modification of Surfaces"

A. Chutjian, M.H. Hecht, O.J. Orient

NASA Tech Brief NPO-17498

"Molecular Beam Epitaxy of  $\text{CrSi}_2$  on Si (111)"

R.W. Fathauer, P.J. Grunthaner, T.L. Lin, D.N. Jamieson, J.H. Mazur

NASA Tech Brief NPO-17438

"Deposition of Pinhole-Free  $\text{CoSi}_2$  Films"

T.L. Lin, R.W. Fathauer, P.J. Grunthaner

NASA Tech Brief NPO-17447

## Electronic Device Technology

### Publications

"New Flange Correction Formula Applied to Interfacial Resistance Measurements of Ohmic Contacts to GaAs"

U. Lieneweg, D.J. Hannaman  
IEEE Electron Dev. Lett. 8 (1988)

"Watt-Level Millimeter-Wave Monolithic Diode-Grid Frequency Multipliers"

R.J. Hwu, C.F. Jou, W.W. Lam, B. Hancock, U. Lieneweg, N.C. Luhman, Jr., J. Maserjian, D.B. Rutledge  
Rev. Sci. Instrum. 59 (1988)

"Oxidation of Silicon with a 5 eV  $O^-$  Beam"

M.H. Hecht, O.J. Orient, A. Chutjian, R.P. Vasquez  
Appl. Phys. Letters 54, 421 (1989)

"Reactions of Fast Ground-State Oxygen Atoms with Surfaces"

O.J. Orient, A. Chutjian and E. Murad  
Physical Review A (1989)

"Barrier Height Enhancement of InP-Based  $n\text{-Ga}_{0.47}\text{In}_{0.53}\text{As}$  Schottky Barrier Diodes Grown by Molecular Beam Epitaxy"

J.H. Kim, S.S. Li, L. Figueroa  
Electron. Lett. 24, 687 (1988)

"PN Junction Properties of AlGaAs/GaAs Grown on GaAs-Coated Si Substrates by Liquid Phase Epitaxy"

S. Sakai, S.S. Chang, S. Nakamura, R.V. Ramaswamy, J.H. Kim, J.K. Liu, G. Radhakrishnan, J. Katz  
MRS Proceedings, Vol. 144, paper W-9.3 (1988)

### Presentations

"B-I-N Diodes"

U. Lieneweg  
Solid State THz Sources Workshop, Pasadena, CA, August, 1988

"Oxidation of Silicon with a 5 eV  $O^-$  Beam"

M.H. Hecht, O.J. Orient, A. Chutjian, R.P. Vasquez  
19th IEEE Semiconductor Interface Specialists Conference, San Diego, December, 1988

"Interaction of Low-Energy  $O^-(^2P)$  and  $O(^3P)$  Beams with a  $\text{MgF}_2$  Surface"

A. Chutjian, O.J. Orient, E. Murad  
41st Annual Gaseous Electronics Conference, MN, October, 1988



"Experimental Investigations of Low-Energy (4-40 eV) Collisions of  $O^-(^2P)$  and  $O(^3P)$  Atoms with Surfaces"

A. Chutjian, O.J. Orient, E. Murad

Space Operations, Autonomy and Robotics Conference, Johnson Space Flight Center, Houston, July, 1989

"High Kinetic Energy vs. High Temperature: Studies in Reactions of Fast O Atoms"

A. Chutjian, O.J. Orient, E. Murad

Symposium on High Temperature and Materials Chemistry, Berkeley, CA, October, 1989

### **Patents and New Technology Reports**

"Formula Gives Better Contact-Resistance Values"

U. Lieneweg, D.J. Hannaman

NASA Tech Brief NPO-17096

"Tunable Submillimeter Wave Generator"

A.C. Gossard, J. Maserjian

NPO-17754

"Use of Variable-Energy Ion Beams for Surface Modification"

A. Chutjian, M.H. Hecht, O.J. Orient

NPO-17498 (patent pending)

## **Molecular Electronics**

### **Publications**

"Determination of Protein Orientation on Surfaces with X-ray Photoelectron Spectroscopy"

R. Margalit, R.P. Vasquez  
J. Protein Chem. (in press)

"X-ray Photoelectron Spectroscopy Study of Surface Protein Orientation"

R. Margalit, R.P. Vasquez  
Second International Conference of Molecular Electronics and Biocomputers, Moscow, USSR, September 11-18, 1989 (to be published by Kluwer Publishing, The Netherlands)

"Use of X-ray Photoelectron Spectroscopy in the Measurement of Protein Orientation on Surfaces"

R.P. Vasquez, R. Margalit  
Thin Solid Films (submitted)

### **Presentations**

"A Study of Protein Self-Assembly Using X-ray Photoelectron Spectroscopy"

R. Margalit and R. Vasquez  
AAAS Annual Meeting, San Francisco, CA, January 14-19, 1989

"Hemoproteins for Optical Processing Applications"

R. Margalit  
Engineering Foundation Conference on Molecular Electronics: Science and Technology, Hawaii, February 1989.

"Metalloproteins Thin Films"

R. Margalit and R. Vasquez  
Protein Society Meeting, Seattle, WA, July 29, - August 2, 1989

"X-ray Photoelectron Spectroscopy Study of Surface Protein Orientation"

R. Margalit, R.P. Vasquez  
Second International Conference of Molecular Electronics and Biocomputers, Moscow, USSR, September 11-18, 1989

"Evidence for Oriented Protein Surface Layers using X-Ray Photoelectron Spectroscopy"

R. Margalit, R. P. Vasquez  
UCLA Symposium on Protein and Pharmaceutical Engineering, Park City, UT, January 17-22, 1989

"Metalloprotein Thin Films"

R. Margalit, R. P. Vasquez  
IEEE Conference on Medical and Biological Sciences, Seattle, WA, November 11-17, 1989

"X-ray Photoelectron Spectroscopy Study of Hemoprotein Thin Films"

R. Margalit, R. P. Vasquez  
The Protein Society, Seattle, WA, July 29 - August 22, 1989

---

## **Patents and New Technology Reports**

"Indicator for Pseudomonas Bacteria"

R. Margalit

NASA Tech Brief NPO-17653



## Overview

This section concentrates on optoelectronic materials and devices. Optical processing is included in the section on Computer Architecture and Subsystems. Optoelectronic devices, which generate, detect, modulate, or switch electromagnetic radiation are being developed for a variety of space applications. The program includes spatial light modulators, solid state lasers, optoelectronic integrated circuits, infrared detectors, photovoltaic devices, nonlinear optical materials and devices, and fiber optics.

## 1988-1989 Major Technical Achievements

### Spatial Light Modulators

- **Demonstrated** two different photo-optic effects based on combining nipi and multiple quantum well structures grown by MBE. Results indicate that high-performance, optically addressed, spatial light modulators (O-SLM's) can be achieved using these effects in appropriate structures.

### Lasers

- **Fabricated** InGaAsSb/AlGaAsSb lasers capable of room temperature operation at 2.1  $\mu\text{m}$ . This wavelength capability is important for LIDAR observations of planetary atmospheres.
- **Demonstrated** the monolithic integration of second-order, e-beam-written gratings with AlGaAs/GaAs lasers. The gratings serve as spatially selective filters to substantially reduce near and far-field emission widths from broad-area lasers. Such improvement of the coherence of broad-area lasers is important for high-power applications. The work was done in a collaboration with the National Nanofabrication Laboratory of Cornell University where the e-beam writing was performed.
- **Demonstrated** double heterostructure (DH) AlGaAs/GaAs stripe-geometry lasers on Si substrates with world-record performance. The DH stripe lasers exhibited the highest peak power (184 mW/facet) on record for this heteroepitaxial system. These laser structures were prepared by hybrid growth of migration-enhanced molecular beam epitaxy (MEMBE) followed by MOCVD.
- **Demonstrated** graded-index separate-confinement heterostructure (GRINSCH) AlGaAs/GaAs single quantum-well lasers on Si by migration enhanced molecular beam epitaxy (MEMBE) followed by MOCVD in collaboration with Hughes Research Lab. These lasers exhibited the highest peak power (450 mW/facet) on record for low-threshold-current quantum-well lasers in this important heteroepitaxial system.

- **Fabricated** high-quality pseudomorphic InGaAs/AlGaAs single quantum well lasers on GaAs substrates. These lasers have state-of-the-art threshold currents, and the observed quantum efficiency and output power represent world records for this materials system.

### Optoelectronic Materials and Characterization

- **Developed** a laboratory electron beam lithography system based on a scanning electron microscope.
- **Developed** a low temperature cathodoluminescence system based on a novel optical fiber light collection system. The U.S. patent on this system has been issued.
- **Fabricated** quantum wires in the GaAs (AlGaAs) system by diffusion induced disordering.
- **Developed** a novel cathodoluminescence based technique for measurement of electronic diffusion lengths.
- **Developed** a new multiband formalism for analysis of band structure and optical matrix elements in quantum dot and quantum wire structures.
- **Invented** several new paramagnetic organic molecules and established their spectroscopy and chemical reactivity patterns.
- **Established** a new mechanism for ferromagnetic coupling of electron spins in organic materials; such interactions are critical to the design of magnetic materials.
- **Invented** a new class of organic polymers that can be doped to produce a large number of spins; preliminary measurements (SQUID) indicate significant, cooperative magnetic behaviors.

### Optoelectronic Integrated Circuits

- **Fabricated** the first 10x10 array of neuron devices for neural network applications as part of a JPL/Caltech collaboration. The integrated device contains a detector, LED emitter and an amplifier at each pixel.

### Infrared Detectors

- **Demonstrated** the reproducibility of Germanium Blocked Impurity Band (GeBIB) devices for far infrared wavelengths. Initial measured performance demonstrates response to beyond 200 microns, 4.5 A/W at 102 microns, and a dark current of less than 1000 e/s. This effort is being conducted at JPL, Caltech, University of Rochester and the Rockwell Science Center in Anaheim, California.

- **Developed** a novel MBE process capable of growing single-crystal columns of  $\text{CoSi}_2$  embedded in a Si matrix. This process enables the fabrication of a new Schottky-like IR detector with augmented quantum efficiency, "the layered internal photoemission sensor" (LIPS).
- **Fabricated** InAs PIN photodiodes in collaboration with Cincinnati Electronics showing 75% quantum efficiency at 77 K, with cutoff wavelengths of 2.8-3.0  $\mu\text{m}$ , and with an areal yield of better than 85%. The quantum efficiency measurements were made with illumination through the GaAs substrate.
- **Fabricated** InAs tunnel diodes by MBE on GaAs substrates with 14:1 peak to valley ratio. This result demonstrates the ability to achieve high doping  $p^+n^+$  InAs diodes with high quality on GaAs. It is also a precursor result for fabricating InAs doping superlattices for LWIR detectors.
- **Fabricated** IrSi/Si p-type Schottky-diode detectors using MBE, which permits the growth of uniform, single-phase silicide layers. These detectors exhibit infrared photoresponse out to 8  $\mu\text{m}$ , and offer the potential of extended-range focal-plane arrays compatible with Si-based technology.
- **Extended** the range of infrared response of  $\text{CoSi}_2$  Schottky diodes by the use of MBE doping technology, which permits the precise placement of high-density doping layers adjacent to the metal-semiconductor interface. This technology may be applied to other silicide IR sensors as well.

## Nonlinear Optical Materials and Characterization

- **Synthesized** new organic and organometallic materials with very large second order optical nonlinearities exhibiting powder second harmonic generation efficiencies 2000X that of urea, the industry standard; **demonstrated** the feasibility of using these materials in thin film electro-optic modulators.
- **Synthesized** new processable polymers with large nonresonant third-order nonlinear optical susceptibilities having very low optical losses (1000X less than polyacetylene), a critical feature for photonic applications.
- **Demonstrated** optical limiters for laser eye protection based on silicon containing naphthalocyanine dyes. These materials are normally transparent in the visible spectrum, but limit throughput of high intensity optical radiation to a few microjoules or less depending on the pulse duration.
- **Developed** theoretical and experimental strategies for designing molecular level optical, electronic or photonic devices based on electron transfer.
- **Achieved** net gain coefficients for beam coupling in photorefractive GaAs of up to 140% using four-wave mixing. These results illustrate the potential for development of cascable optical processors using photorefractive GaAs.
- **Demonstrated** interaction of mutually incoherent light beams in photorefractive GaAs crystals, illustrating the potential of optical processing using incoherent light beams of different wavelengths in semiconductors.

## **Fiber Optics**

- Developed concept of real-time interface for 100 mbit FDDI network. Will allow free mixing of voice, video, and data on fiber optic token ring network.

## **Photovoltaic Technology**

- **Demonstrated** for the first time the growth of diamond-like carbon thin films by electron cyclotron resonance plasma deposition. The technology has application to high temperature devices and to advanced optical coatings for sensor protection in space.



## **Spatial Light Modulators**

### **Publications**

"An Optically Controlled Absorption Modulator Based on State Filling of  $\text{In}_x\text{Ga}_{1-x}\text{As/GaAs}$  Quantum Wells"

J.M. Iannelli, J. Maserjian, B.R. Hancock, P.O. Andersson, F.J. Grunthner  
Applied Physics Letters 54, 301 (1989)

"An Optically Controlled Reflection Modulator using GaAs/AlGaAs nipi/Multiple Quantum Well Structures"

K.K. Law, P.O. Holtz, R.J. Simes, L.A. Coldren, A.C. Gossard, J. Maserjian, J.L. Merz  
Optics Letters 14, 230 (1989)

### **Presentations**

"Spatial Light Modulation in GaAs"

L.J. Cheng, G. Gheen, and D.T.H. Liu

*Invited paper*, Technical Digest of the Topical Conference on Spatial Light Modulation and Applications, Lake Tahoe, NV, June 15-17, 1988 (Optical Society of America, Washington, DC) p.44

"On the Progress of the Liquid Crystal Television Spatial Light Modulator"

T.H. Chao, H.K. Liu

Technical Digest of the Topical Conference on Spatial Light Modulation and Applications, Lake Tahoe, NV, June 15-17, 1988 (Optical Society of America, Washington, DC) p.138

"Optically Addressed Spatial Light Modulators by MBE Grown nipi/MQW Structures"

J. Maserjian, P.O. Andersson, B.R. Hancock, J.M. Iannelli, S.T. Eng, F.J. Grunthner  
OSA Topical Meeting on Spatial Light Modulators, Lake Tahoe, NV, June 15-17, 1988

### **Patents and New Technology Reports**

"Spatial Light Modulation in Gallium Arsenide"

L.J. Cheng, G.O. Gheen, A. Partovi

NASA Tech Brief NPO-17228

"Photodiode-Coupled Multiple Quantum Well Modulator"

J. Maserjian, S.T. Eng

NASA Tech Brief NPO-16298

"Monolithic III-V/Silicon Modulator"

J. Maserjian, S.T. Eng

NASA Tech Brief NPO-16916

"Photovoltaic-Driven Strain-Layer-Superlattice Modulator"

J. Maserjian

NASA Tech Brief NPO-16915 (patent pending)

"Photovoltaic-Driven Quantum Well Modulator"

J. Maserjian

NASA Tech Brief NPO-16914 (patent pending)

"Electroabsorption Monolithic Modular Array"

J.Katz, et. al.

NASA Tech Brief NPO-16481, U. S. Patent No. 4,744,616

"Improvements on Photovoltaic-Driven Multiple Quantum Well Modulator"

J. Maserjian

NPO-17357 (patent pending)

"Multiple Quantum Well Optical Modulator"

J. Maserjian

CIT 1881-A, U.S. Patent No. 4,818,079

"All Optical Photochromic Spatial Light Modulators"

D. N. Beratan, J. W. Perry

NASA Tech Brief NPO-17612

## **Lasers**

### **Publications**

"High-Power Low-Threshold Graded-Index Separate Confinement Heterostructure AlGaAs Single Quantum Well Lasers on Si Substrates"

J.H. Kim, R.J. Lang, G. Radhakrishnan, J. Katz, A. Narayanan, R.R. Craig  
Applied Physics Letters 55, 1492 (1989)

"High-Power AlGaAs/GaAs DH Stripe Lasers on GaAs-on-Si Prepared by Migration-Enhanced Molecular Beam Epitaxy"

J.H. Kim, G. Radhakrishnan, A. Nouhi, J.K. Liu, J. Katz  
Japan Journal of Applied Physics 28, 791 (1989)

"Narrow Far Fields from Extended-Window Broad Area Lasers"

R.J. Lang, S. Forouhar, J. Cser, J. Katz, P. Gavrilovic, J. Williams, W. Stutius, A. Chin  
Applied Physics Letters 53, 1372 (1988)

"Measurement of a Relaxation Resonance, Damping and Nonlinear Gain from Sidebands in the Field Spectrum of a 1.3  $\mu\text{m}$  InGaAs DFB Laser"

R.J. Lang, H.P. Mayer, W. Elsasser, H. Schweizer, A.P. Mozer  
Applied Physics Letters 54, 1845 (1989)

"Modulation Bandwidth of GaAs/AlGaAs Single Quantum Well Lasers Operating at the Second Quantized State"

A. Larsson and L. Lindstrom  
Applied Physics Letters 54, 884 (1989)

"Highly Coherent Long Cavity GaAs/AlGaAs Single Quantum Well Lasers"

A. Larsson, P.A. Andrekson, B. Johnson, L. Lindstrom  
IEEE Journal of Quantum Electronics 25, 2013 (1989)

"High Speed  $\text{Ga}_{0.47}\text{In}_{0.53}\text{As}/\text{InP}$  Infrared Schottky Barrier Photodiodes"

J.H. Kim, S.S. Li, L. Figueroa, T.F. Carruthers, R.S. Wagner  
Electron. Lett. 24, 1067 (1988)

"High-Speed InP-Based  $\text{In}_x\text{Ga}_{1-x}\text{As}$  Schottky Barrier Infrared Photodiodes for Fiber-Optic Communications"

J.H. Kim, S.S. Li, L. Figueroa, T.F. Carruthers, R.S. Wagner  
J. Appl. Phys., 64, 6536 (1988)

"High Peak Power Low Threshold AlGaAs/GaAs Stripe Layer Diode on GaAs-on-Si by Hybrid Migration-enhanced MBE and MOCVD Growth"

J. H. Kim, A. Nouhi, G. Radhakrishnan, R. J. Lang, J. Katz  
Appl. Phys. Lett., Vol. 53, pp. 1248-1250, 1988

" $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}/\text{Al}_{0.05}\text{Ga}_{0.95}\text{As}$  Light-Emitting diodes on GaAs-Coated Si Substrates Grown by Liquid Phase Epitaxy"

S. Sakai, S.S. Chang, R.V. Ramaswamy, J.H. Kim, G. Radhakrishnan, J. Katz  
Appl. Phys. Lett. 53, 1203 (1988)

"Narrow Far Fields From Extended-Window Broad Area Lasers"

R. J. Lang, S. Forouhar, J. Cser, J. Katz, P. Gavrilovic, J. Williams, W. Stutius, A. Chin

Appl. Phys. Lett., Vol. 53, pp. 1372-1374, 1988

"An Exact Formulation of Coupled-Mode Theory for Coupled-Cavity Lasers"

R. J. Lang, A. Yariv

IEEE J. Quantum Electron., Vol. QE-24, pp 66-72, 1988

"High-Power AlGaAs/GaAs DH Stripe Laser Diodes on GaAs-on-Si Prepared by Migration-enhanced Molecular Beam Epitaxy"

J. H. Kim, G. Radhakrishnan, A. Nouhi, J. K. Liu, R. J. Lang, J. Katz

Jap. J. Appl. Phys., Vol. 28, pp. 791-796, 1989

"Measurement of Relaxation Resonance, Damping and Nonlinear Gain From Sidebands in the Field Spectrum of a 1.3 mm InGaAsP DFB Laser"

R. J. Lang, H.-P. Mayer, W. Elsässer, H. Schweizer, A. P. Mozer

Appl. Phys. Lett., Vol. 54, pp. 1845-1847, 1989

"A High-Speed In-Based InGaAs Schottky Barrier Infrared Photodiode for Fiber-Optic Communications"

J.H. Kim, S.S. Li, L. Figueroa, T.F. Carruthers

Proceedings of the IEEE Electronic Devices and Materials Symposium, Taiwan, August 29-31, 1988, p. 192

"High-Peak-Power Low-Threshold AlGaAs/GaAs Strip Laser Diodes on Si Substrates by Hybrid MBE and MOCVD Growth"

J.H. Kim, A. Nouhi, G. Radhakrishnan, J. Katz

SPIE Proceedings Vol. 945, 155 (1988)

"High-Power AlGaAs/GaAs Stripe Laser Diode on GaAs-on-Si Substrates Grown by Migration-Enhanced Molecular Beam Epitaxy"

J.H. Kim, A. Nouhi, G. Radhakrishnan, R.J. Lang, J. Katz

Proceedings of the 11th IEEE International Semiconductor Laser Conference, Boston, MA, August 28 - September 1, 1988, p. 154

## **Presentations**

"GaInAsSb/AlGaAsSb Injection Lasers for Remote Sensing Applications"

S. Forouhar, J. Cody, J. Katz

SPIE Vol. 1062, 16 (1989)

"GaAs/AlGaAs Corner Reflector Laser for Monolithic Integration"

M. Hagberg, A. Larsson, S.T. Eng

15th European Conference on Optical Communication, Gothenburg, Sweden, September 10-14, 1989

"High-Power Low-Threshold Graded-Index Separate-Confinement Heterostructure Single Quantum Well Lasers on Si Substrates Prepared by Migration-Enhanced Molecular Beam Epitaxy"

J.H. Kim, R.J. Lang, G. Radhakrishnan, J.Katz, A. Narayanan, R.R. Craig  
IEEE LEOS '89 Annual Conference, Orlando, FL, October, 15-20, 1989

"Spectral and Dynamic Properties of GaAs/AlGaAs Single Quantum Well Lasers"

A. Larson, P.A. Andrekson, B.Jonsson, L. Linstrom  
15th European Conference on Optical Communication, Gothenburg, Sweden, September 10-14, 1989

"Separated Large Optical Cavity GaAsAs/GaAs Diode Lasers"

S.J. Lee, R.V. Ramaswamy, P.S. Zory, L. Figueroa, J.H. Kim  
IEEE LEOS '89 Annual Conference, Orlando FL, October 15-20, 1989

"Diffraction-Coupled-Output Lasers for High Optical Powers"

S. Forouhar, R.J. Lang, J. Cser, J. Katz  
IEEE International Semiconductor Laser Conference, Boston, MA, July, 1988

"Semiconductor Laser Technology for Remote Sensing Experiments"

J.Katz  
SPIE OE/LASE '88, Los Angeles, January 11-15, 1988

"High Peak Power AlGaAs/GaAs Stripe Laser Diodes on GaAs-on-Si Substrates Grown by Migration-Enhanced Molecular Beam Epitaxy"

J.H. Kim, A. Nouhi, G. Radhakrishnan, R.J. Lang, J. Katz  
IEEE International Semiconductor Laser Conference, Boston, MA, August 28 - September 1, 1988

"A High-Speed InP-Based InGaAs Schottky Barrier Infrared Photodiode for Fiber-Optic Communications"

J.H. Kim, S.S. Li, L. Figueroa, T.F. Carruthers  
IEEE Electronic Devices and Materials Symposium, Taiwan, August 29-31, 1988

## **Patents and New Technology Reports**

"Laser Receiver Using Luminescent Light Trapping"

J. W. Perry, A. H. Zewail, T. Cole  
NPO-17916

"Multiperiod Grating Surface-Emitting Laser"

R.J. Lang  
NPO-18054

"Surface Emitting Laser with Integrated Multilayer Reflector"

R.J. Lang  
NPO-17763 (patent pending)

"High-Power AlGaAs/GaAs Single Quantum Well Lasers on Migration-Enhanced Molecular Beam Epitaxial GaAs-Coated Si Substrates"

J.H. Kim, R.J. Lang, G. Radhakrishnan, J. Katz  
NPO-17988

"Annular Bragg Grating Surface Emitting Laser"  
R.J. Lang  
NASA Tech Brief NPO-17912

"Unstable Resonator DBR Laser"  
R.J. Lang  
NASA Tech Brief NPO-17906

# Optoelectronic Materials and Characterization

## Publications

"Optoelectronic Materials, Devices Packing and Interconnects"  
T.E. Batchman, R.F. Carson, R.L. Gallawa, H.J. Wojtunik, Editors  
Proc. SPIE 836, p.169 (1988)

"Intersubband Auger Recombination and Population Inversion in Quantum Well Subbands"  
S. Borenstain, J. Katz  
Physical Review B39, 10852 (1989)

"Cathodoluminescence System for a Scanning Electron Microscope Using a Novel Optical Fiber Light Collection System"  
M. Hoenk, K.J. Vahala  
Rev. Sci. Instrum., 60, (2) 226 (1989)

"Nanometer Scale Wire Structures Fabricated by Diffusion Induced Disordering of a GaAs (AlGaAs) Quantum Well"  
H.A. Zarem, P.C. Sercel, M.E. Hoenk, J.A. Legens, K.J. Vahala  
Appl. Phys. Lett., 54, 2692 (1989)

"Direct Determination of the Ambipolar Diffusion Length in GaAs/AlGaAs Heterostructures by Cathodoluminescence"  
H.A. Zarem, P.C. Sercel, J.A. Lebens, L.E. Eng, A. Yariv, K.J. Vahala  
Appl. Phys. Lett., 55, 1647 (1989)

"Effect of Aluminum Mole Fraction on Carrier Diffusion Lengths and Lifetimes in AlGaAs"  
H.A. Zarem, J.A. Lebens, K.B. Nordstrom, P.C. Sercel, S. Sanders, L.E. Eng, A. Yariv, K.J. Vahala  
Appl. Phys. Lett., 55, #23 (1989)

"Multiband Envelope Theory in a Spherical Representation: Application of a Super-J Basis to Centrosymmetric Semiconductor Heterostructures"  
K.J. Vahala, P.C. Sercel  
Phys. Rev. Lett. (submitted)

"Quantum Wires and Quantum Dots: Physics and Applications"  
K.J. Vahala  
Proceedings of the American Electrochemical Society Annual Meeting, Chicago, IL. (1988)

"Disorder of a GaAs-AlGaAs Quantum Well as a Technique for Fabricating Quantum Wires"  
H.A. Zarem, P.C. Sercel, M. Hoenk, A. Yariv, K.J. Vahala  
Proceedings of the Topical Meeting on Quantum Wells for Optics and Optoelectronics"  
Salt Lake City, UT (Paper TuA5) (1989)

"Nanometer Scale Bandgap Modulation by Disorder of a GaAs-AlGaAs Quantum Well"  
H.A. Zarem, P.C. Sercel, M. Hoenk, A. Yariv, K.J. Vahala  
Proceedings of the Quantum Electronics and Laser Science Conference, Baltimore, MD, (1989)

"Quantum Wire and Quantum Dot Lasers"

K.J. Vahala

Proceedings of the Quantum Electronics and Laser Science Conference, (1989)

"Quantum Wire and Quantum Dots in Semiconductor Lasers"

K.J. Vahala

*Invited* paper, Gordon Conference on Nonlinear Optics and Lasers, Wolfeboro, NH, (1989)

"Quantum Wire and Quantum Dot Semiconductor Lasers: Physics and Fabrication"

K.J. Vahala

Proceedings of the European Conference on Optical Communication, Gothenberg, Sweden (1989)

"Quantum Confinement for Optoelectronic Devices: Beyond the Conventional Quantum Well"

K.J. Vahala

Proceedings of the Conference on Optical Fiber Communication, San Francisco, CA, (1990)

"Optical Properties of Nanostructures for Semiconductor Lasers"

K.J. Vahala

*Invited* paper, APS March, Meeting, Anaheim, CA, (1990)

"A Novel Technique for the Direct Determination of Carrier Diffusion Lengths in GaAs/GIGaAs Heterostructures Using Cathodoluminescence"

P.C. Sercel, H. Zarem, J. Legens, L. Eng, A. Yariv, K.J. Vahala

International Electron Devices Meeting, Washington D.C. (paper #11.3) (1989)

"Cyclobutanediyls: A New Class of Localized Biradicals. Synthesis and EPR Spectroscopy"

R. Jain, M.B. Sponsler, F.D. Coms, D.A. Dougherty

J. Am. Chem. Soc. 110, 1988, 1356

"1,3-Diphenyl-1,3-cyclopentanediy: A Remarkably Stable Localized Biradical"

F.D. Coms, D.A. Dougherty

Tetrahedron Lett. 29, 1988, 3753

"Matrix-Isolation Decay Kinetics of Triplet Cyclobutanediyls. Observation of Both Arrhenius Behavior and Heavy-Atom Tunneling in C-C Bond-Forming Reactions"

M.B. Sponsler, R. Jain, F.D. Coms, D.A. Dougherty

J. Am. Chem. Soc. 111, 1989, 2240

"Diphenylbicyclo[2.1.0]pentane. A Persistent Hydrocarbon with a Very Weak C-C Bond"

F.D. Coms, D.A. Dougherty

J. Am. Chem. Soc. 111, 1989, 6894



## **Presentations**

"Quantum Wires and Quantum Dots: Physics and Applications"

K.J. Vahala

*Invited* presentation, Proceedings of the American Electrochemical Society Annual Meeting, Chicago, IL (1988)

"Disorder of a GaAs-AlGaAs Quantum Well as a Technique for Fabricating Quantum Wires"

H.A. Zarem, P.C. Sercel, M. Hoenk, A. Yariv, K.J. Vahala

Proceedings of the Topical Meeting on Quantum Wells for Optics and Optoelectronics" Salt Lake City, UT (Paper TuA5) (1989)

"Nanometer Scale Bandgap Modulation by Disorder of a GaAs-AlGaAs Quantum Well"

H.A. Zarem, P.C. Sercel, M. Hoenk, A. Yariv, K.J. Vahala

Proceedings of the Quantum Electronics and Laser Science Conference, Baltimore, MD (1989)

"Quantum Wire and Quantum Dot Lasers"

K.J. Vahala

*Invited* presentation, Proceedings of the Quantum Electronics and Laser Science Conference (1989)

"Quantum Wire and Quantum Dots in Semiconductor Lasers"

K.J. Vahala

*Invited* presentation, Gordon Conference on Nonlinear Optics and Lasers, Wolfeboro, NH (1989)

"Quantum Wire and Quantum Dot Semiconductor Lasers: Physics and Fabrication"

K.J. Vahala

*Invited* presentation (MoA3-2), Proceedings of the European Conference on Optical Communication, Gothenberg, Sweden (1989)

"Quantum Confinement for Optoelectronic Devices: Beyond the Conventional Quantum Well"

K.J. Vahala

*Invited* presentation, Proceedings of the Conference on Optical Fiber Communication, San Francisco, CA (1990)

"A Novel Technique for the Direct Determination of Carrier Diffusion Lengths in GaAs/GlGaAs Heterostructures Using Cathodoluminescence"

P.C. Sercel, H. Zarem, J. Legens, L. Eng, A. Yariv, K.J. Vahala

International Electron Devices Meeting, Washington D.C. (paper #11.3) (1989)

## **Optoelectronic Integrated Circuits**

### **Publications**

"Monolithically Integrated Two-Dimensional Arrays of Optoelectronic Threshold Devices for Neural Network Applications"

J.H. Kim, S.H. Lin, J. Katz, D. Psaltis  
SPIE Proceedings 1043, 44 (1989)

"Integration of High-Gain Double Heterojunction of GaAs Bipolar Transistors with a LED for Optical Neural Network Applications"

S.H. Lin, J.H. Kim, J. Katz, D. Psaltis  
Proceedings of the IEEE Cornell Conference on Advanced Concepts in High-Speed Semiconductor Devices and Circuits, Ithaca, NY, August 7-9, 1989

"System Issues Relating to Laser Diode Requirements for VLSI Holographic Optical Interconnects"

E. Bradley, P.K.L. Yu, A.R. Johnston  
Opt. Eng. 28, 155 (1989)

### **Presentations**

"Monolithically Integrated Two-Dimensional Arrays of Optoelectronic Threshold Devices for Neural Network Applications"

J.H. Kim, S.H. Lin, J. Katz, D. Psaltis  
SPIE Conference on Diode Technology and Applications, Los Angeles, CA, January 18-20, 1989

"Optimum Design of High-Gain AlGaAs/GaAs Double Heterojunction Bipolar Transistors for Optoelectronic Integrated Circuit Applications"

J.H. Kim, S.H. Lin, J. Katz, D. Psaltis  
IEEE LEOS '89 Annual Conference, Orlando, FL, October 15-20, 1989

"Integration of High-Gain Double Heterojunction GaAs Bipolar Transistors with a LED for Optical Neural Network Applications"

S.H. Lin, J.H. Kim, J. Katz, D. Psaltis  
IEEE Cornell Conference on Advanced Concepts in High-Speed Semiconductor Devices and Circuits, Ithaca, NY, August 7-9, 1989

### **Patents and New Technology Reports**

"Monolithic Two-Dimensional Arrays of Optoelectronic Threshold Devices for Neural Networks"

D. Psaltis, J. Katz, J.H. Kim, S.H. Lin  
NASA Tech Brief NPO-17652

"High-Gain AlGaAs/GaAs Double Heterojunction Darlington Phototransistors for Neural Network Applications"

J.H. Kim, S.H. Lin  
NPO-18101

## **Infrared Detectors**

### **Publications**

"Infrared Pre-Detection Dynamic Range Compression via Photorefractive Crystals"  
H.K. Liu, L.J. Cheng  
Applied Optics, 27, 1006 (1988)

"Tunable Quantum Well Infrared Detector"  
K.L. Doughty, P.O. Holtz, R.J. Simes, A.C. Gossard, J.L. Merz, J. Maserjian  
Proceedings of OSA Topical Meeting on Optics and Optoelectronics, Salt Lake City, UT,  
March 6, 1989

### **Presentations**

"Tunable Quantum Well Infrared Detector"  
K.L. Doughty, P.O. Holtz, R.J. Simes, A.C. Gossard, J.L. Merz, J. Maserjian  
OSA Topical Meeting on Optics and Optoelectronics, Salt Lake City, UT, March 6, 1989

"Use of Ultra-Thin, Highly Doped Layers to Extend the Cut-off Wavelength in Schottky-Diode Infrared Sensors"  
R.W. Fathauer, T.L. Lin, J.M. Iannelli, P.J., Grunthaner, J. Maserjian  
European MRS, Strasbourg, France, May 30- June 2, 1989

"LWIR Detector Research and Development at JPL"  
J. Maserjian  
*Invited* presentation, Superlattice/Quantum Well Detectors Workshop, Los Alamos, NM,  
August 10, 1989

"Silicon-Compatible Infrared Sensors"  
P. J. Grunthaner  
AVS Thin Film and Surface Science Open House, Jet Propulsion Laboratory, California  
Institute of Technology, Pasadena, CA, January 23, 1989

"Extrinsic Germanium Blocked Impurity Band Detectors"  
T.N. Krabach, J.E. Huffmann, D.M. Watson  
Ames Low Background Infrared Detector Workshop, NASA Ames Research Center,  
Moffet Field, CA., January, 1989

### **Patents and New Technology Reports**

"Dynamic Range Compression/Expansion of Light Beams by Photorefractive Crystals"  
L.J. Cheng, H.K. Liu  
NASA Tech Brief NPO-17140, U. S. Patent No. 4,772,785

"Stacked Silicide-Silicon for Infrared Detector"  
J. Maserjian  
NASA Tech Brief NPO-17194 (patent pending)

"Tunable Quantum Well Infrared Detector"  
J. Maserjian  
NASA Tech Brief NPO-17361 (patent pending)

"Alternate Gradient Photodetector"  
A.W. Overhauser, J. Maserjain  
NASA Tech Brief NPO-17235 (patent pending)

"Plasma-Enhanced Internal Photoemission (PIP) Long Wave Infrared (LWIR) Detector"  
J. Maserjian  
NPO-18053

"Long-Wavelength Infrared Detector"  
R. P. Vasquez  
NASA Tech Brief NPO-17543

"Dynamic-Range Compression for Infrared Imagery"  
L.J. Cheng, H.K. Liu  
NASA Tech Brief NPO-17140, U.S. Patent No. 4,772,785

"A Novel  $p^+-Si_{1-x}Ge_x/p-Si$  LWIR Detector Fabricated by Molecular Beam Epitaxy"  
T.L.Lin  
NPO-17950

"Integrated Optic Spectrometer"  
R.J. Lang  
NASA Tech Brief NPO-17733

"Superlattice Long-Wavelength Infrared Sensors"  
R.W. Fathauer  
NASA Tech Brief NPO-17713

"Infrared Multiquantum Well Phototransistor"  
S. Borenstain  
NPO-17980

"Nitric Oxide Enhances Charge Coupled Devices"  
M. H. Hecht  
NASA Tech Brief NPO-17281

"Back-Surface Illuminated CCD with Ir"  
M. H. Hecht  
NASA Tech Brief NPO-17327

"Deposition of Pinhole-Free  $CoSi_2$  Film"  
T.L. Lin, R.W. Fathauer, P.J. Grunthaner  
NASA Tech Brief NPO-17447

"Molecular Beam Epitaxy of CrSi<sub>2</sub> on Si (111)"  
R.W. Fathauer, T.L. Lin, P.J. Grunthaner  
NASA Tech Brief NPO-17438

"Making Submicron CoSi<sub>2</sub> Structures on Silicon Substrates"  
K.W. Nieh, T.L. Lin, R.W. Fathauer  
NASA Tech Brief NPO-17736

## **Nonlinear Optical Materials and Characterization**

### **Publications**

"Index Grating Lifetime in Photorefractive GaAs"

L.J. Cheng, A. Partovi

Applied Optics, 27, 1760 (1988)

"Cross-Polarization Two Beam Coupling in Photorefractive GaAs Crystals"

L.J. Cheng, P. Yeh

Optics Letters, 13, 50 (1988)

"Photorefractive Effects in GaAs"

L.J. Cheng, G. Gheen

Proc. SPIE 836, p. 169 (1988)

"Cross Polarization Multiwave Mixings in Semiconductors"

L.J. Cheng, P. Yeh

"Proceedings of the International Conference on Nonlinear Optics, Cong, County Mayo, Ireland, May 3-6, 1988", ed. V.J. Corcoran (STS Press, McLean, VA) , p. 225

"Photorefractive Gain in GaAs under a DC Electric Field"

D.T.H. Liu, L.J. Cheng, M.F. Rau, F.C. Wang

Applied Physics Letters, 53, 1369 (1988)

"DC Electric Field Effect on Cross Polarization Four-Wave Mixing in GaAs"

L.J. Cheng, D.T.H. Liu

Technical Digest of the Annual Meeting of the Optical Society of America, October 31-November 4, 1988, p.161

"Photorefractive Gain in GaAs under a DC Electric Field"

D.T. H. Liu, L.J. Cheng, M.F. Rau, F.C. Wang

Applied Physics Letters, 53, 1369 (1988)

"Efficient Photorefractive Gain Under a DC Electric Field"

D.T.H. Liu, L.J. Cheng

Technical Digest of the Annual Meeting of the Optical Society of America, October 31-November 4, 1988, p.137

"Two Beam Coupling Gain in Undoped GaAs with Applied DC Electric Field and Moving Grating"

D.T.H. Liu, L.J. Cheng, A.E. Chiou, P. Yeh

Optics Communications, 72, 384 (1989)

"Fanning in Undoped GaAs Under a DC Electric Field"

D.T.H. Liu, L.J. Cheng

Technical Digest of the Conference on Lasers and Electro-Optics, Baltimore, MD, April 24-28, 1989

"Two-Beam Coupling Gain in Undoped GaAs with Applied DC Electric Field and Moving Grating"

D.T.H. Liu, L.J. Cheng, A.E. Chiou, P. Yeh

Optics Communications, 72, 384 (1989)

"Polarization Properties of Degenerate Four-Wave Mixing in GaAs"

D.T.H. Liu, L.J. Cheng

J. Opt. Soc. Am. B. 6, 1558 (1989)

"Photorefractive Incoherent to Coherent Converter"

J. Yu, D. Psaltis, R. Johnson, A. Marrakchi, A.R. Tanguay Jr.

Chapter of a book, "Topics in Applied Physics: Photorefractive Materials and Applications II" (Springer Verlag, 1989)

"Second-Order Nonlinear Optical Properties of Diiron Alkenylidyne Complexes"

J.A. Bandy, H.E. Bunting, M.H. Garcia, M.L.H. Green, S.R. Marder, M.E. Thompson, D. Bloor, P.U. Kolinsky, R.J. Jones, J.W. Perry

J. Organomet. Chem. (submitted for publication 1989)

"The Synthesis of Optically Active Ferrocenyl Compounds with Second-Order Optical Nonlinearities"

H. E. Bunting, M.L.H. Green, S. R. Marder, D. Bloor, P. U. Kolinsky, R. J. Jones

J. Chem. Soc., Chem. Commun. (submitted for publication 1989)

"The Synthesis of Ferrocenyl Compounds with Second-Order Optical Nonlinearities"

M. L. H. Green, S. R. Marder, M. E. Thompson, D. Bloor, P. U. Kolinsky, R. J. Jones

J. Organomet. Chem. (submitted for publication 1989)

"New Organometallic Solids"

M. L. H. Green, J. Qin, D. O'Hare, H. E. Bunting, M. E. Thompson, S. R. Marder, K. Chatakondur

Pure and Appl. Chem., 61, 817 (1989)

"Organometallic Salts with Large Second-Order Optical Nonlinearities: (E)-1-Ferrocenyl-2-(4-N-Methylpyridinium) Ethylene Salts"

S. R. Marder, J. W. Perry

J. Am. Chem. Soc. (submitted for publication 1989)

"Third-Order Susceptibilities of Soluble Polymers Derived from the Ring-Opening Metathesis Copolymerization of Cyclooctatetraene and 1,5-Cyclooctadiene"

S. R. Marder, J. W. Perry, F. L. Klavetter, R. H. Grubbs

Chem. Materials, 1, 171 (1989)

"Synthesis of Organic Salts with Large Second-Order Optical Nonlinearities"

S. R. Marder, J. W. Perry, W. P. Schaefer

Science, 245, 626 (1989)

"The Synthesis of Organometallic Compounds with Second-Order Optical Non-linearities"

J. A. Bandy, H. E. Bunting, M. H. Garcia, M. L. H. Green, S. R. Marder, M. E.

Thompson, D. Bloor, P. U. Kolinsky, R. J. Jones

In "Organic Materials for Nonlinear Optics," R. A. Hann and D. Bloor, eds, p. 225 (The Royal Society of Chemistry, London, 1989)

"The Synthesis of Ferrocenyl Compounds with Second-Order Optical Non-linearities"

J. A. Bandy, H. E. Bunting, M. L. H. Green, S. R. Marder, M. E. Thompson, D. Bloor, P. U. Kolinsky, R. J. Jones

In "Organic Materials for Nonlinear Optics," R. A. Hann and D. Bloor, eds, p. 219 (The Royal Society of Chemistry, London, 1989)

"Structural Dependence of the  $\pi$ -Electron Contributions to the Optical Second Hyperpolarizability of Nonlinear Conjugated Organic Molecules"

D. N. Beratan, M. A. Lee, D. W. Allender, S. Risser  
SPIE Proceedings, 1080, in press (1989)

"Optical Limiting in Solutions of Metallophthalocyanines and Naphthalocyanines"

D. R. Coulter, V. M. Miskowski, J. W. Perry, T. H. Wei, E. W. Van Stryland, D. J. Hagan  
SPIE Proceedings, 1105, 42 (1989)

"The Synthesis and Third-Order Optical Nonlinearities of Soluble Polymers Derived from the Ring Opening Metathesis Copolymerization of Cyclooctatetraene and 1,5-Cyclooctadiene"

S. R. Marder, J. W. Perry, F. L. Klavetter and R. H. Grubbs  
In "Organic Materials for Nonlinear Optics," R. A. Hann, D. Bloor, eds, p. 288 (The Royal Society of Chemistry, London, 1989)

"Second and Third Order Nonlinear Optical Properties of Conjugated Molecules and Polymers"

J. W. Perry, A. E. Stiegman, S. R. Marder, D. R. Coulter, D. N. Beratan, D. E. Brinza, F. L. Klavetter, R. H. Grubbs  
SPIE Proceedings, 971, 17 (1988)

"Second and Third Order Nonlinear Optical Properties of End-Capped Acetylenic Oligomers"

J. W. Perry, A. E. Stiegman, S. R. Marder, D. R. Coulter  
In "Organic Materials for Nonlinear Optics," R. A. Hann, D. Bloor, eds., p. 189 (The Royal Society of Chemistry, London, 1989)

## **Presentations**

"DC Electric Field Effect on Cross Polarization Four-Wave Mixing in GaAs"

L.J. Cheng, D.T.H. Liu

Technical Digest of the Annual Meeting of the Optical Society of America, October 31-November 4, 1988, p. 161

"Efficient Photorefractive Gain Under a DC Electric Field"

D.T.H. Liu, L.J. Cheng

Technical Digest of the Annual Meeting of the Optical Society of America, October 31-November 4, 1988, p. 137

"Fanning in Undoped GaAs Under a DC Electric Field"

D.T.H. Liu, L.J. Cheng

Technical Digest of the Conference on Lasers and Electro-Optics, Baltimore, MD, April 24-28, 1989

"Optical Limiting in Organometallic Macrocyclic Dyes"

D. R. Coulter

DARPA Technical Steering Committee Meeting on Eye and Sensor Protection Against the Battlefield Laser Threat, Alexandria, VA, January, 1989



"Optical Limiting in Solutions of Metallophthalocyanines and Naphthalocyanines"  
D. R. Coulter, V. M. Miskowski, J. W. Perry, T. H. Wei, E. W. Van Stryland, D. J. Hagan  
SPIE, Symposium on Materials for Optical Switches, Isolators and Limiters, Orlando, FL, March, 1989

"Optical Limiting in Solutions of Metallophthalocyanines and Naphthalocyanines"  
D. R. Coulter, V. M. Miskowski, J. W. Perry, T. H. Wei, E. W. Van Stryland, D. J. Hagan  
SPIE Proceedings, 1105, 42 (1989)

"The Synthesis and Nonlinear Optical Properties of Poly-n-butyl Cyclooctatetraene"  
C. B. Gorman, E. J. Ginsburg, S. R. Marder, R. H. Grubbs, J. W. Perry  
ACS National Meeting, Dallas, Texas, April, 1989

"New Organic and Organometallic Materials for Second-Order Nonlinear Optics"  
S. R. Marder, J. W. Perry, W. P. Schaefer  
Engineering Foundation Conference on "Molecular Electronics -- Science and Technology"  
Keauhou Kona, Hawaii, February 1989

"The Synthesis and Third-Order Optical Nonlinearities of Soluble Polymers Derived from the Ring Opening Metathesis Copolymerization of Cyclooctatetraene and 1,5-Cyclooctadiene"  
S. R. Marder, J. W. Perry, F. L. Klavetter and R. H. Grubbs  
In "Organic Materials for Nonlinear Optics," R. A. Hann, D. Bloor, eds, p. 288 (The Royal Society of Chemistry, London, 1989)

"Nonlinear Optical Materials"  
J. W. Perry  
JPL-TRW Technology Exchange Program, Jet Propulsion Laboratory, Pasadena, CA, October, 1988

"Second and Third Order Nonlinear Optical Properties of Conjugated Molecules and Polymers"  
J. W. Perry, A. E. Stiegman, S. R. Marder, D. R. Coulter, D. N. Beratan, D. E. Brinza, F. L. Klavetter, R. H. Grubbs  
SPIE Proceedings, 971, 17 (1988)

"Second and Third Order Nonlinear Optical Properties of End-Capped Acetylenic Oligomers"  
J. W. Perry, A. E. Stiegman, S. R. Marder and D. R. Coulter  
In "Organic Materials for Nonlinear Optics," R. A. Hann, D. Bloor, eds., p. 189 (The Royal Society of Chemistry, London, 1989)

"Synthesis and Characterization of Processable Organic and Organometallic Materials with Large Second and Third Order Optical Nonlinearities and Fast Response"  
J. W. Perry  
1st International Symposium on Nonlinear Optical Polymers for Soldier Survivability,  
U.S. Army Natick Research, Development and Engineering Center, Natick, MA, June, 1989

"The Synthesis of Organometallic Compounds with Second-Order Optical Non-Linearities" J. A. Bandy, H. E. Bunting, M. H. Garcia, M. L. H. Green, S. R. Marder, M. E. Thompson, D. Bloor, P. U. Kolinsky, R. J. Jones  
In "Organic Materials for Nonlinear Optics," R. A. Hann and D. Bloor, eds, p. 225, (The Royal Society of Chemistry, London, 1989)

"The Synthesis of Ferrocenyl Compounds with Second-Order Optical Non-Linearities" J. A. Bandy, H. E. Bunting, M. L. H. Green, S. R. Marder, M. E. Thompson, D. Bloor, P. U. Kolinsky, R. J. Jones  
In "Organic Materials for Nonlinear Optics," R. A. Hann and D. Bloor, eds, p. 219 (The Royal Society of Chemistry, London, 1989)

"Structural Dependence of the Pi-Electron Contributions to the Optical Second Hyperpolarizability of Nonlinear Conjugated Organic Molecules"  
D. N. Beratan, M. A. Lee, D. W. Allender, S. Risser  
SPIE Proceedings, 1080, in press (1989)

### **Patents and New Technology Reports**

"Optical Signal Using the Photorefractive Effects in Semiconductor Etalons"  
L.J. Cheng, A. Partovi, E.M. Garmire  
NASA Tech Brief NPO-17460

"Net Photorefractive Gain in Gallium Arsenide"  
L.J. Cheng, T.H. Liu  
NASA Tech Brief NPO-17626

"Organometallic Salts with Large Second Order Nonlinear Optical Susceptibilities"  
S. R. Marder, J. W. Perry  
NASA Tech Brief NPO-17730

"Compounds Generate Optical Second Harmonics"  
S. R. Marder, J. W. Perry  
NASA Tech Brief NPO-17731

"Diphenylpolynes for Nonlinear Optical Devices"  
A. E. Stiegman, J. W. Perry, D. R. Coulter  
NASA Tech Brief NPO-17572

## **Fiber Optics**

### **Publications**

"A Miniaturized Space-Potential DC Electric Field Meter"

A.R. Johnston, H. Kirkham

IEEE Trans. Power Delivery, 4, 1253 (1989)

"Optically Powered Data Link for Power System Applications"

H. Kirkham, A.R. Johnston

IEEE Trans. Power Delivery, 4, 1997 (1989)

### **Presentations**

"Fiber Optics for Distribution Automation"

H. Kirkham, A. Johnston, D. Roessler

Proceedings of 4th IASTED, Valencia, Spain, July 4-7, 1989

"Implementation of a Tactical Voice/Data Network Over FDDI"

L.A. Bergman, F. Halloran, J. Martiniz

MILCOM' 88, San Diego, CA, October 23-26, 1988

"Overview of JPL/NASA Fiber Optic LAN Research"

L.A. Bergman

Information Gatekeepers MFOC '88, Los Angeles, CA, December 5-8, 1988

### **Patents and New Technology Reports**

"Fast Asynchronous Data Communication via Fiber Optics"

L. Bergman, R. Tell

NASA Tech Brief NPO-16972

## **Photovoltaic Technology**

### **Publications**

"Amorphous Silicon Germanium Alloy Film Deposition with In Situ Plasma Diagnostics"  
Y.H. Shing, J.W. Perry, C.E. Allevato  
Solar Cells, 24, 353 (1988)

"Diagnostics of Silane and Germane Radio Frequency Plasmas by Coherent Anti-Stokes Raman Spectroscopy"  
J.W. Perry, Y.H. Shing, C.E. Allevato  
Appl. Phys. Lett. 52, 2022 (1988)

"Optical Emission Diagnostics of Electron Cyclotron Resonance and Glow Discharge Plasmas for a-Si:H and a-SiC:H Film Depositions"  
C.L. Yang, Y.H. Shing, C.E. Allevato  
Proc. 20th IEEE Photovoltaic Specialists Conf., 202 (1988)

"Silane and Germane Plasma Diagnostics for Depositing Photosensitive a-SiGe:H Films"  
Y.H. Shing, J.W. Perry, C.E. Allevato  
Proc. 20th IEEE Photovoltaic Specialists Conf., 224 (1988)

"Electron Cyclotron Resonance Deposition of a-Si:H and a-C:H Films"  
Y.H. Shing, C.L. Yang, C.E. Allevato, F.S. Pool  
Materials Research Society Symposium Proceedings (1989)

"Electron Cyclotron Resonance Deposition and Plasma Diagnostics of a-Si:H and a-C:H Films"  
Y.H. Shing  
Solar Cells (1989) (submitted)

### **Presentations**

"Optical Emission Diagnostics of Electron Cyclotron Resonance and Glow Discharge Plasmas for a-Si:H and a-SiC:H Film Depositions"  
C.L. Yang, Y.H. Shing, C.E. Allevato  
20th IEEE Photovoltaic Specialists Conference, Las Vegas, NV, September 26-30, 1988

"Silane and Germane Plasma Diagnostics for Depositing Photosensitive a-SiGe:H Films"  
Y.H. Shing, C.L. Yang, C.E. Allevato, F.S. Pool  
Materials Research Society Symposium, November, 1988

"Microwave Assisted Plasma Deposition of Amorphous Alloys"  
Y.H. Shing  
American Vacuum Society Thin Film and Surface Science Chapter Open House at the Jet Propulsion Laboratory, Pasadena, CA, January 23, 1989

"Electron Cyclotron Resonance Deposition of Diamond and Diamond-Like Films"  
Y.H. Shing and F.S. Pool  
Eleventh International Vacuum Congress, Cologne, West Germany, September 25-29, 1989

"Electron Cyclotron Resonance and Glow Discharge Deposition of a-Si:H, a-C:H and a-SiC:H Films"

Y.H. Shing, C.E. Allevato, C.L. Yang, F.S. Pool

Solar Energy Research Institute Amorphous Silicon Subcontractors Meeting (1989)

"Electron Cyclotron Resonance Deposition of a-Si:H and a-C:H Films"

Y.H. Shing, C.L. Yang, C.E. Allevato, F.S. Pool

Materials Research Society Symposium Proceedings (1989)

### **Patents and New Technology Reports**

"Detection of Gas-Phase Polymerization in Silane and Germane Plasmas"

Y.H. Shing, J.W. Perry, C.E. Allevato

NASA Tech Brief NPO-17779

"Photovoltaic Hydrogen Sensor"

T. Daud, J. Janesick, J. Lambe

NASA Tech Brief NPO-17124



## Overview

Advanced concepts in hardware, software and algorithms are being pursued for application in next generation space computers and for ground-based analysis of space data. The research program focuses on massively parallel computation, neural networks, and optical processing. Also included are small seed efforts in novel magnetic memories and molecular computation. A common theme is fault tolerance which is required for space applications and for acceptable mean time to failure in massively parallel ground computers.

## 1988-1989 Major Technical Achievements

### Parallel Computation

- The Hypercube Project completed its third generation objective when, in April, the 128-node Mark IIIfp was **assembled and verified**. Many of the 200-plus science and engineering applications that had been run on smaller hypercubes were extended on the large machine, and system timing tests showed that it operated as one of the most powerful supercomputers in the world today. One Caltech physics problem in quantum chromodynamics was computed at a rate of over 700 million floating point operations per second.
- **Demonstrated** Hyperswitch Adaptive Message Routing VLSI chip with a data throughput per channel of 400 Mbits/s and adaptive network reconfiguration for a number of random channel failures. The above tests were verified with a laboratory testbed configuration.
- **Collaborated** on the system development and evaluation of the Hyperswitch Communication Network (HCN) with a large computer company. This multiprocessor computer will result in a machine ready for mission critical large-scale applications.
- **Developed** simulation methods key to complex distributed systems modeling and performance evaluation. This work has the support of the above HCN collaboration.
- **Developed** a conceptual design for a fault-tolerant hypercube which can be implemented as a ground-based hypercube or be used as the basis for a flight hypercube.
- **Developed and demonstrated** a Concurrent Image Processing Executive for the SUN/hypercube high-performance workstation environment.
- During the Voyager Neptune encounter period in August the JPL Image Analysis Systems Group employed an 8-node Mark IIIfp hypercube to **process** the images that were used to create the mosaics and rotational movies that were essential to displaying and understanding the atmospheric dynamics of the planet in near real time. The computational requirements are large; they include photometric correction, corrections for spacecraft navigation and pointing parameters, geometric projections to be used for map registration, creation of mosaics, and analysis of the motions of features in the imagery. Their 8-node machine operated at 60 to 80 times the speed of the computer system used conventionally for these computations, a VAX 8600.

- Four electromagnetic (EM) scattering and radiation analysis programs have been **developed** for the hypercube. These programs are being used to design and analyze metallic structures such as the Global Positioning System Rogue Receiver choke ring antenna. A major emphasis of this EM research effort is developing analysis tools which are particularly suited to a parallel environment such as the finite element parallel partitioning and load balancing algorithms, and the efficient parallel sparse and dense matrix solvers.
- Other applications that have been **developed** include a 2-d electrostatic particle-in-cell plasma simulation, synthetic aperture radar data analysis, radiative transfer calculations for atmospheric parameter retrieval, image processing of multi-spectral data, vortex flow analysis, crustal deformation studies, and complex simulations. These applications typically run with an efficiency of 80 to 95 percent. That means that a program using a 32-node hypercube will run 26 to 30 times faster than one on a single node without accruing substantial penalty for message passing or node synchronization.
- The hypercube is now being **employed** to run large distributed simulations of multi-processor computer systems as a design and analysis tool for future generations of such machines. The Hypercube Project is simulating their next generation communications processor using the Time Warp operating system that has been under development by JPL and UCLA for several years. The implementation allows distributed discrete-event simulations of machines of up to 2048 processing nodes under varying workloads and communication requirements to be run extremely quickly compared to simulations that can be run only on traditional sequential machines.
- **Demonstrated** 4-node MAX multicomputer designed for general purpose, fault-tolerant spacecraft applications. This effort will result in a flight qualifiable, low power, low mass parallel processor suitable for a wide range of missions.
- **Demonstrated** new dataflow software design methodologies for MAX multicomputers that simplify development of flight software.
- **Developing** flight qualifiable designs for two custom VLSI chips supporting the MAX multicomputer.
- **Developing** a custom VLSI chip (300,000 transistors) and overall system for the Human Genome Project. This biological system will have the performance of over 40 Cray-2 supercomputers at 1/1,000 of the cost.

### Neural and Analog Computing

- **Demonstrated** a floating gate field effect transistor with analog memory in VLSI, for the first time using double-poly process (MOSIS), a strong contender as a synapse for electronic neural networks with on-chip learning capability.
- **Designed and fabricated** a wide spectrum of cascable, programmable, CMOS/VLSI synaptic chips with binary to 11-bit resolution, as well as multineuron chips. This has led to transfer of neural nets hardware technology to U.S. industries.



- **Developed** "building blocks" for high speed image processing/pattern recognition applications. The building blocks consist of:
  - **A fabricated** 62x62 thin film, binary, nonvolatile, programmable, high density synaptic array with a nominal feature size of 2 microns based on amorphous chromium silicon alloy system.
  - **A designed and fabricated** 64-neuron CMOS/VLSI "winner-take-all" cascadable chip with a winner lockout feature. It selects the best pattern match in less than 10 microseconds (with an effective search rate of more than  $10^9$  bits/sec for a 64-bit x1000 word memory).
- **Developed** a unique, versatile neurocircuit simulator, a valuable neural net hardware design aid, which takes the realistic hardware component characteristics into account during simulation, for a variety of neural net architectures and algorithms.
- **Demonstrated**, for the first time, Euclidean distance minimization in fully parallel hardware for multidimensional vector quantization. It has been successfully applied to terrain trafficability determination with a 10 to 100 times speed improvement over digital computing approach. This has paved the way for rapid hardware prototyping of several selected neuroprocessors for DoD applications.
- **Made** a major algorithmic/architectural breakthrough allowing a novel neural nets approach to computationally intensive problems of combinatorial optimization (e.g., the famous Traveling Salesman Problem, TSP) using our unique "analog prompting scheme." This has resulted in:
  - A software as well as a hardware **demonstration** of the TSP solutions using the hybrid neuro-computer and the VLSI based neural net system.
  - **Implementation** of a consumer-resource assignment problem, demonstrating for the first time the multiple assignment solution in hardware with a phenomenal speed of a few microseconds.
- **Demonstrated** for the first time, by circuit simulation, that a novel design of our analog resource allocation chip solves a one-to-one assignment problem of 32 tracks to 32 targets (with a search space of over  $10^{35}$  possible solutions) in ~100 microseconds, a 4-orders of magnitude faster response than even an 8-node Mark III hypercube machine.
- **Demonstrated** the high speed performance of a "trained" neuro-processor hardware interfaced with an experimental robotic arm for positioning the end-effector of the arm within the selected work space. The network is trained under supervision with an error-back-propagation algorithm, and executes the inverse kinematics transformation in less than 10 microseconds.

## Neural and Nonlinear Theory

- **Implemented** image enhancement filters and reading rate software on a Sun workstation which was enhanced using high-speed digital hardware to develop a clinical prototype for improving the reading performance of low vision observers using commercially available closed circuit television.
- **Designed and implemented** fast accurate dynamic image analysis of natural scenes based on biological models using a layered neural network to reconstruct the depth map that analyzes the scene across several sensory dimensions, such as texture, position, motion parallax, shape from shading, illumination, and occlusion. Implemented feedforward and feedback connections using nonlinear adaptive thresholding, region growing, changes in optical flow, and Hebbian learning to improve 3D reconstruction.
- **Designed** a dynamic imaging system (based on layered biological neural networks and image enhancement to improve resolution of objects) to be used for mapping out the surfaces of unknown terrain (e.g., planetary imaging, and navigating robotic vehicles close to real-time frame rates).
- **Discovered** a new type of attractor in nonlinear dynamical systems: this attractor, named "Terminal Attractor" ensures infinite local stability of information encoded in neural networks and enables suppression of spurious states in associative memories.
- **Developed** a radically new method for supervised learning using neural networks with non-lipschitzian dynamics. Dramatic increase in the speed of learning (over state-of-the-art back-propagation algorithms) has been achieved, and the methodology enables systematic incorporation of event-driven constraints in real-time.
- **Developed** a new formalism for unsupervised learning from examples presented to a neural network. Each example is considered as an "interpolation node" of the networks velocity field in phase space, thereby enabling automatic clustering for pattern recognition.
- **Discovered** a fundamentally new class of nonlinear dynamical systems: the unpredictable systems with creative dynamics. Such systems are presented in the form of coupled activation and learning dynamical equations whose ability to be spontaneously activated is based upon two pathological characteristics. Firstly, such systems have zero Jacobian. As a result of that, they have an infinite number of equilibrium points which occupy curves, surfaces of hypersurfaces. Secondly, all these equilibrium points become terminal attractors or repellers depending upon the sign of the periodic excitation. Potential applications may range from encryption to machine intelligence.
- **Demonstrated** fast learning algorithms based on adjoint operator theory. The development of learning algorithms is generally based upon the minimization of a "neuromorphic" energy-like function. A fundamental requirement of all currently available approaches is the computation of the gradient of this objective function with respect to the various parameters of the neural architecture such as synaptic weights, neural gains, decay constants, etc. In principle, the computation requires the solution of a system of nonlinear equations for each parameter of the network. Our new methodology enables us to gather all the information required to compute

the energy gradients with respect to all network parameters by solving a single set of (linear) adjoint equations. The information so obtained can also be used to propagate architecture uncertainties (expressed as covariance matrices) to a network response of interest.

- **Discovered** the existence of chaotic oscillations in massively parallel neural networks and developed a new methodology enabling correct recovery of information under concurrently asynchronous operating regimes. The methodology constitutes the first demonstration of true fault-tolerance capabilities in neural networks.
- **Developed** a biologically inspired computational methodology for hyperacute global sensory resolution from a pool of potentially coarse or unreliable single receptors.
- **Demonstrated** that oscillations can serve as local distributed clocks in analog calculations and can encode and label temporal information by several phase and frequency adjusting mechanisms. The methodology is expected to become a cornerstone for applications such as signal pattern search, sequence likelihood estimation and signal presence indication.
- **Developed** smart retina neural network architecture that generates translation and rotation invariant representations of star maps for the JPL neural network star pattern identifier.
- **Completed** the computer simulation for the comparison of the inner- and outer-product algorithms of the Hopfield-type neural net with difference binary data representations. Discovered a unified approach for input data representation.
- **Discovered** the application of the new terminal attractor binary associative (TABAM) neural processing for the reduction or elimination of spurious states. Derived a model for binary data representation for optical implementation and conceived optical architectures for the new model.
- **Demonstrated** the inner-product neural network using a diffuser, a Hughes LCLVSLM, and the LCTVSLM originally developed at JPL.

### Optical Processing

- **Demonstrated** a shortest Hamming distance based optical associative memory breadboard.
  - Suitable for both auto- and hetero-associative recall.
  - Suitable for accurate similarity measure between images.
  - Suitable for radar image processing.

- **Developed** an innovative optical associative memory architecture using opto-electronic light amplifiers.
  - Can be miniaturized.
  - Can be cascaded to multiple layers.
- **Demonstrated** matrix-vector and vector-vector multiplications with large arrays of elements, optical correlation, image substraction, and logic operations using photorefractive GaAs.
- **Demonstrated** spectral imaging of an outdoor scene using an imaging spectrometer breadboard with an acousto-optic tunable filter of TeO<sub>2</sub>.
- **Demonstrated** the feasibility of using GaAs crystals as interaction media for high-speed image correlation and convolution applications.
- **Achieved** matrix-vector operations using four-wave mixing in photorefractive compound semiconductors.
- **Demonstrated** an optical pseudocolor encoding method to enhance visibility of interesting features of an image using colors representing different signal densities and object brightness.
- **Achieved** auto- and hetero-associative memory using a two-dimensional optical logic gate.
- **Demonstrated** for the first time phase conjugate interferometers using photorefractive GaAs, which have potentials to be utilized in high-speed optical computing, novelty filters, and moving target tracking.
- **Established** the feasibility of using photorefractive GaAs as a real-time dynamic volume holographic medium for optical and image processing applications.

## Data Storage

- **Designed** complete VLSI memory chips (with I/O) using Vertical Bloch Line (VBL) pairs as memory elements, for use with nonvolatile, radiation hard magnetic garnet technology. Fabrication is proceeding under contract on devices with 10 Mbit/cm<sup>2</sup> and 25 Mbit/cm<sup>2</sup> densities. Test chips have been designed and fabricated (and are undergoing testing) for evaluating operation of the storage cells (i.e. minor loops). Magnetostatic performance simulations were conducted for a VBL output detector and major line gates (i.e. output gates).
- **Invented** a magnetic-Hall effect random access memory which offers densities greater than SRAM, sub-100 nanosecond access time, nonvolatility, low power consumption, and SEU and radiation hardness.
- **Simulated** performance of Hall sensors in the magnetic-Hall effect random access memory, accounting for certain fabrication variations and domain variations in the magnetic layer. Measurements of large-scale InSb Hall sensors were made for comparison.

- **Established** a new data storage laboratory with magnetic and magneto-optical effect test equipment.

### **Molecular Computation**

- There has been much activity, both theoretical and experimental in the area of strategies for designing molecular level optical, electronic or photonic devices based on electron transfer. The molecular shift register memory concept developed last year has been generalized to yield a number of device architectures. In addition, experiments have been under way to measure rates and quantum yields of single and two step intramolecular electron transfer reactions as a function of chemical structure and environment.

## **Parallel Computation**

### **Publications**

"General Purpose Concurrent Processing for Space Applications"

R. Bunker, B. Lewis, R. Rasmussen

AIAA Conference on Parallel Computation, California State University at Fullerton, April, 1988

"Designing Expert Systems for Modeling Complex Computer Systems"

E. Upchurch, K. Raman, K. Ranai

19th Modeling and Simulation Conference, Pittsburgh, PA, May, 1988

"Designing Expert Systems for Modeling Complex Computer Systems"

E. Upchurch, K. Raman, K. Ranai

ISA Transactions, Vol. 28, No. 1, 1989

"Parallel Joins on the Mark III Hypercube"

E. Upchurch, K. Cloud, D. Curkendall, A. Loomis, J. Geiselman

4th Conference on Hypercube Concurrent Computers, Monterey, CA, 1989

"Object-Oriented Modeling and Expert Systems"

E. Upchurch

20th Modeling and Simulation Conference, Pittsburgh, PA, May, 1989

"Modeling Internode Communications for Hypercube Architectures"

E. Upchurch, D. Neuse

SCS Summer Simulation Conference, Austin, TX, July, 1989

"Modeling Parallel Relational Database Join Algorithms on the Mark III Hypercube"

E. Upchurch, K. Cloud, D. Curkendall, A. Loomis

20th Modeling and Simulation Conference, Pittsburgh, PA, May, 1989

"A PAWS-Based Fault Simulation Model for the Mark III Hypercube"

E. Upchurch, E. Chow, J. Peterson, H. Madan

International Workshop On Fault Tolerance in Multiprocessors, Urbana, IL, June, 1989

"A Fault Simulation Model for the Mark III Hypercube"

E. Upchurch, E. Chow, J. Peterson, H. Madan

IEEE - International Workshop on Hardware Fault Tolerance in Multiprocessors, June, 1989

"A High-Speed Message-Driven Communication Architecture"

J. Peterson, E. Chow, H. Madan

Proceedings of the 1988 ACM International Conference on Supercomputing, July, 1988

"Stepping Up to Multiprocessing - Is It Worth the Hassle?"

J. Peterson, R. Ferraro, K. Kim, D. Mizell

Panel: AIAA Computers in Aerospace VII Conference, October, 1989

"Plasma Simulations on the Mark III Hypercube"

P. C. Liewer, R. W. Gould, G. F. Fox, V. K. Decyk, J. M. Dawson

Third Conference on Hypercube Concurrent Computers and Applications, 1988

"Plasma Particle Simulations on the Mark III Hypercube"

P. C. Liewer, V. K. Decyk, J. M. Dawson, G. F. Fox

Proceedings of the 6th International Conference on Mathematical Modeling (Pergamon, 1988)

"A Universal Concurrent Algorithm for Plasma Particle-in-Cell Simulation Codes"

P. C. Liewer, V. Decyk

Division of Plasma Physics, APS, Hollywood, FL, November, 1988

"Application of Hypercube Computers to Plasma Particle-in-Cell Simulation Codes"

P. C. Liewer, V. Decyk

Fourth International Conference on Supercomputing, Santa Clara, CA, May, 1989

"A General Concurrent Algorithm for Plasma Particle in Cell Simulation Codes"

P.C. Liewer, V.K. Decyk

Computational Physics (in press)

"Hypercube Matrix Computation Task--Report for 1986-1988"

R. H. Calalo, W. A. Imbriale, N. Jacobi, P. C. Liewer, T. G. Lockhart, G. A. Lyzenga, J. R. Lyons, F. Manshadi, J. E. Patterson

JPL Publication 88-31, August, 1988

"Hypercube Parallel Architecture Applied to Electromagnetic Scattering Analysis"

R. Calalo, T. Cwik, W. Imbriale, P. Liewer, T. Lockhart, G. Lyzenga, J. Patterson

Third IEEE Conference on Electromagnetic Field Computation, Bethesda, MD, December, 1988

"Hypercube Matrix Computation Task, Research in Parallel Computational Electromagnetics"

R. H. Calalo, T. Cwik, R. D. Ferraro, W. A. Imbriale, N. Jacobi, P. C. Liewer, T. G. Lockhart, G. A. Lyzenga, S. Mulligan, J. W. Parker, J. E. Patterson

Report for 1988-1989, November 1, 1989

"Hypercube Parallel Architecture Applied to Electromagnetic Scattering Analysis"

R. Calalo, T. Cwik, W. Imbriale, P. Liewer, T. Lockhart, G. Lyzenga, J. Patterson

Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March, 1989

"A General Concurrent Algorithm for Plasma Particle-in-Cell Simulation Codes"

V. Decyk, J. Dawson, P. Liewer, G. Fox

Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March, 1989

"Numerical Algorithms for the Hypercube Concurrent Processor"

J. Patterson, F. Manshadi, R. Calalo, P. Liewer, W. Imbriale, J. Lyons

Proceedings of the 6th International Conference on Mathematical Modeling, (Pergamon, 1988)

"Application of the Hypercube Parallel Processor to a Large-Scale Method of Moments Code"

F. Manshadi, P. C. Liewer, J. Patterson

IEEE 1988 Aerospace Applications Conference, February, 1988

- "Performance of the Colliding Pucks Simulation on the Time Warp Operating System (Part I: Asynchronous Behavior and Sectoring)"  
P. Hontalas, B. Beckman, M. Di Loreto, L. Blume, P. Reiher, K. Sturdevant, L. Van Warren, J. Wedel, F. Wieland, D. Jefferson  
Distributed Simulation 1989, Society for Computer Simulation, March, 1989
- "Benchmarking the Time Warp Operating System with a Computer Network Simulation"  
M. Presley, M. Ebling, F. Wieland, J. Jefferson  
Distributed Simulation 1989, Society for Computer Simulation, March, 1989
- "Distributed Combat Simulation and Time Warp: The Model and its Performance"  
F. Wieland, L. Hawley, A. Feinberg, M. Di Loreto, L. Blume, P. Reiher, B. Beckman, P. Hontalas, S. Bellenot, D. Jefferson  
Distributed Simulation 1989, Society for Computer Simulation, March, 1989
- "The Performance of a Distributed Combat Simulation on the Time Warp Operating System"  
F. Wieland, L. Hawley, A. Feinberg, M. Di Loreto, L. Blume, J. Rufles, B. Beckman, P. Hontalas, S. Bellenot  
Concurrency: Practice and Experience, Vol. 1, No. 1, September, 1989
- "An Ant Foraging Model on the Time Warp Operating System"  
M. Ebling, M. Di Loreto, M. Presley, F. Wieland, D. Jefferson  
Distributed Simulation 1989, Society for Computer Simulation, March, 1989
- "A General Framework for Complex Time-Driven Simulations on Hypercubes"  
D. L. Meier, K. L. Cloud, J. C. Horvath, J. D. Allan, W. H. Hammond, H. A. Maxfield  
Proceedings of 4th Conference on Hypercube, Concurrent Computers, and Application, Monterey, CA, March, 1989
- "Electro-Optical Adaptive Switching Network for the Hypercube Computer"  
E. Chow, J. Peterson  
Proceedings SPIE - The International Society for Optical Engineering, January, 1988
- "Hyperswitch Network for the Hypercube Computer"  
E. Chow, H. Madan, J. Peterson, D. Grunwald, D. Reed  
IEEE/ACM - 15th Annual International Symposium on Computer Architecture, May, 1988
- "Computer Performance Comparisons of DNA Sequences"  
E. Chow  
International Supercomputer Conference, February, 1989
- "The Mark IIIfp Hypercube Concurrent Processor Architecture"  
J. Tuazon, J. Peterson, M. Pniel  
The Third Conference on Hypercube Concurrent Computers and Applications, January, 1988



"Computer-Aided Design of Dependable Mission Critical Systems"  
R. Iyer, B. Randell, J. Dugan, J. Peterson, J. Lala, W. Hiemerding  
Panel: IEEE - 19th International Symposium on Fault-Tolerant Computing, June, 1989

"PAWS:-A Performance Engineering Tool"  
K. Raman, K. Ranai, K. Ong, E. Upchurch  
19th Modeling and Simulation Conference, Pittsburgh, PA, May, 1988

"Concurrent Image Processing Executive"  
M. Lee  
JPL Highlight, Jet Propulsion Laboratory, Pasadena, CA, 1988

"Concurrent Image Processing"  
M. Lee  
Fourth Conference on Hypercube Concurrent Computers and Applications, Monterey, CA,  
March, 1989

"VBIB Device Driver Design"  
M. Lee  
Fourth Conference on Hypercube Concurrent Computers and Applications, Monterey, CA,  
March, 1989

"Neptune Imaging on the Hypercube"  
M. Lee  
The Leading Edge Superperformance Computing Conference, Pasadena, CA, December  
18-19, 1989

"On the Feasibility of a Spaceborne Fault-Tolerant Hypercube"  
D.A. Rennels, J.A. Rohr, F.P. mathur, H.H. Luong  
Proceedings of the AIAA Computers in Aerospace VII Conference, Monterey, CA,  
October 3-5, 1989

"On the Feasibility of a Fault-Tolerant Spaceborne Parallel Processor (FTSPP)"  
D.A. Rennels, J.A. Rohr  
JPL Publication D-6718 (JPL internal document) Jet Propulsion Laboratory, Pasadena,  
CA, August, 1989

## **Presentations**

"General Purpose Concurrent Processing for Space Applications"  
R. Bunker, B. Lewis, R. Rasmussen  
*Invited* presentation, AIAA Conference on Parallel Computation, California State  
University at Fullerton, April, 1988

"Electro-Optical Adaptive Switching Network for the Hypercube Computer"  
E. Chow, J. Peterson  
*Invited* presentation, SPIE, The International Society for Optical Engineering, January,  
1988

"Hyperswitch Network for the Hypercube Computer"  
E. Chow, H. Madan, J. Peterson, D. Grunwald, D. Reed  
*Invited* presentation, IEEE/ACM 15th Annual International Symposium on Computer  
Architecture, May, 1988

- "Computer Performance Comparisons of DNA Sequences"  
E. Chow  
*Invited* presentation, International Supercomputer Conference, February, 1989
- "A High Speed Message-Driven Communication Architecture"  
J. Peterson, E. Chow, H. Madan  
*Invited* presentation, The 1988 ACM International Conference on Supercomputing, July, 1988
- "Stepping Up to Multiprocessing - Is It Worth the Hassle?"  
J. Peterson, R. Ferraro, K. Kim, D. Mizell  
*Invited* panel, AIAA Computers in Aerospace VII Conference, October, 1989
- "Designing Expert Systems For Modeling Complex Computer Systems"  
E. Upchurch, K. Raman, K. Ranai  
19th Modeling and Simulation Conference, Pittsburgh, PA, May, 1988
- "A Fault Simulation Model for the Mark III Hypercube"  
E. Upchurch, E. Chow, J. Peterson, H. Madan  
*Invited* presentation, IEEE International Workshop on Hardware Fault Tolerance in Multiprocessors, June, 1989
- "Parallel Joins on the Mark III Hypercube"  
E. Upchurch, K. Cloud, D. Curkendall, A. Loomis, J. Geiselman  
4th Conference on Hypercube Concurrent Computers, Monterey, CA, 1989
- "Object-Oriented Modeling and Expert Systems"  
E. Upchurch  
20th Modeling and Simulation Conference, Pittsburgh, PA, May, 1989
- "Modeling Internode Communications for Hypercube Architectures"  
E. Upchurch, D. Neuse  
SCS Summer Simulation Conference, Austin, TX, July, 1989
- "Modeling Parallel Relational Database Join Algorithms on the Mark III Hypercube"  
E. Upchurch, K. Cloud, D. Curkendall, A. Loomis  
20th Modeling and Simulation Conference, Pittsburgh, PA, May, 1989
- "A PAWS-Based Fault Simulation Model for the Mark III Hypercube"  
E. Upchurch, E. Chow, J. Peterson, H. Madan  
International Workshop On Fault Tolerance in Multiprocessors, Urbana, IL, June, 1989
- "Computer-Aided Design of Dependable Mission Critical Systems"  
R. Iyer, B. Randell, J. Dugan, J. Peterson, J. Lala, W. Heimerdinger  
*Invited* panel, IEEE 19th International Symposium on Fault-Tolerant Computing, June, 1989
- "Fault-Tolerance in Large Snooping-Cache Multiprocessors"  
J.A. Rohr, D.A. Rennels  
International Workshop on Hardware Fault-Tolerance in Multiprocessors, Urbana, IL, June 19-20, 1989

"Ray Tracing on the Hypercube"

J. Goldsmith, J. Salmon

Poster presentation, Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January, 1988

"PAWS: A Performance Engineering Tool"

K. Raman, K. Ranai, K. Ong, E. Upchurch

19th Modeling and Simulation Conference, Pittsburgh, PA, May, 1988

"A Universal Concurrent Algorithm for Plasma Particle-in-Cell Simulation Codes"

P. C. Liewer, V. K. Decyk, J. M. Dawson, G. C. Fox

The Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988

"Plasma Particle Simulations on the Mark III Hypercube"

P. C. Liewer, V. K. Decyk, J. M. Dawson, G. C. Fox

Proceedings of the 6th International Conference on Mathematical Modeling (Pergamon, 1988)

"Application of Hypercube Computers to Plasma Particle-in-Cell Simulation Codes"

P.C. Liewer, V.K. Decyk

Fourth International Conference on Supercomputing, Santa Clara, CA, May, 1989

"Plasma Simulations on the Mark III Hypercube"

P. C. Liewer, R. W. Gould, G. C. Fox, V. K. Decyk, J. M. Dawson

Third Conference on Hypercube Concurrent Computers and Applications, 1988

"A Universal Concurrent Algorithm for Plasma Particle-in-Cell Simulation Codes"

P. C. Liewer, V. K. Decyk

Division of Plasma Physics, American Physical Society, Hollywood, FL, November, 1988

"Numerical Algorithms for the Hypercube Concurrent Processor"

J. Patterson, F. Manshadi, R. Calalo, P. Liewer, W. Imbriale, J. Lyons

Proceedings of the 6th International Conference on Mathematical Modeling, Pergamon, 1988

"Electromagnetic Scattering Analysis on a Hypercube Parallel Architecture"

J. E. Patterson, P. C. Liewer, R. H. Calalo, F. Manshadi

High Speed Computing Session of the SPIE Innovative Science and Technology Symposium, Los Angeles, CA, January 11-12, 1988

"Hypercube Electromagnetic Interactive Analysis Workstation"

J. E. Patterson, T. Cwik

IEEE Antennas and Propagation Society Workshop on Computer Applications in Electromagnetic Education, San Jose, CA, June 25, 1988

"Concurrent Processing for Electromagnetics"

J. E. Patterson

University of Utah, Salt Lake City, UT, May, 1989

"Computation of Electromagnetic Scattering on a Hypercube"

J. E. Patterson, T. Cwik, R. D. Ferraro, W. A. Imbriale, N. Jacobi, P. C. Liewer, T. G. Lockhart, G. A. Lyzenga  
IEEE Antennas and Propagation and URSI Joint Meeting, San Jose, CA, June, 26-30, 1989

"Concurrent Electromagnetic Scattering Analysis"

J. Patterson, T. Cwik, R. D. Ferraro, J. Jacobi, P. C. Liewer, T. G. Lockhart, G. A. Lyzenga, J. W. Parker  
AIAA Computers in Aerospace VII Conference and Exhibit, Monterey, CA, October 3-5, 1989

"Hypercubes for Electromagnetic Solution"

J. Patterson  
Northrup, Palos Verdes, CA, October 24, 1989

"Electromagnetic Interactive Analysis Workstation"

R. Calalo, T. Cwik, R. D. Ferraro, W. A. Imbriale, N. Jacobi, P. C. Liewer, T. G. Lockhart, G. A. Lyzenga, S. Mulligan, J. W. Parker, J. E. Patterson  
Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March 6-8, 1989

"Application of the Hypercube Parallel Processor to a Large-Scale Method of Moments Code"

F. Manshadi, P. C. Liewer, J. Patterson  
IEEE 1988 Aerospace Applications Conference, February, 1988

"Finite Difference Time Domain Solution of Electromagnetic Scattering on the Hypercube"

R. H. Calalo, J. R. Lyons, W. A. Imbriale  
The Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988

"Hypercube Parallel Architecture Applied to Electromagnetic Scattering Analysis"

R. Calalo, T. Cwik, W. Imbriale, P. Liewer, T. Lockhart, G. Lyzenga, J. Patterson  
Third IEEE Conference on Electromagnetic Field Computation, Bethesda, MD, December, 1988

"Hypercube Parallel Architecture Applied to Electromagnetic Scattering Analysis"

R. Calalo, T. Cwik, W. Imbriale, P. Liewer, T. Lockhart, G. Lyzenga, J. Patterson  
Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March, 1989

"A General Concurrent Algorithm for Plasma Particle-in-Cell Simulation Codes"

V. Decyk, J. Dawson, P. Liewer, G. Fox  
Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March, 1989

"A General Framework for Complex Time-Driven Simulations on Hypercubes"

D. L. Meier, K. L. Cloud, J. C. Horvath, J. D. Allan, W. H. Hammond, H. A. Maxfield  
Proceedings of 4th Conference on Hypercube, Concurrent Computers, and Applications, Monterey, CA, March, 1989

"Concurrent Image Processing"

M. Lee

Fourth Conference on Hypercube Concurrent Computers and Applications, Monterey, CA, March, 1989

"VBIB Device Driver Design"

M. Lee

Fourth Conference on Hypercube Concurrent Computers and Applications, Monterey, CA, March, 1989

"Neptune Imaging on the Hypercube"

M. Lee

The Leading Edge Superperformance Computing Conference, December, 1989

"The Mark III Hypercube Concurrent Processor Architecture"

J. Tuazon, J. Peterson, M. Pniel

*Invited* presentation, The Third Conference on Hypercube Concurrent Computers and Applications, January, 1988

"Matrix Solutions to Radiation and Scattering Problems Using A Hypercube Parallel Processor"

T. Cwik, J. E. Patterson

URSI Meeting, Boulder, CO, January, 1989

"Constructing Matrix Green's Functions for Radiation and Scattering Problems"

T. Cwik, J. E. Patterson, T. G. Lockhart

IEEE Antennas and Propagation and URSI Joint Meeting, San Jose, CA, June 26-30, 1989

"Solution of Large or Time Consuming Problems on the Hypercube Computer"

T. Cwik, J. E. Patterson

IEEE Antennas and Propagation and URSI Joint Meeting, San Jose, CA, June 26-30, 1989

"Parallel Processing and Supercomputer Performance in Computational Electromagnetics"

T. Cwik

National Science Foundation Workshop, Cambridge, MA, July 27, 1989

"Computational Electromagnetics on the Hypercube Parallel Computer"

T. Cwik, R. D. Ferraro, W. A. Imbriale, N. Jacobi, T. G. Lockhart, G. A. Lyzenga, J. W. Parker, J. E. Patterson

Progress in Electromagnetic Research Symposium (PIERS), Cambridge, MA, July 25-26, 1989

"Synthetic Aperture Radar Processing Using the Hypercube Concurrent Architecture"

D. A. Simoni, B. A. Zimmerman, J. E. Patterson, C. Wu, J. C. Peterson

Fourth Conference on Hypercube Computers and Applications, Monterey, CA, March 6-8, 1989

"Towards a Parallel 3D Finite Element Code for EM Analysis on the Mark III Hypercube"

R. D. Ferraro, G. A. Lyzenga, T. Cwik, P. C. Liewer, J. E. Patterson, N. Jacobi

First General Meeting of the Topical Group on Computational Physics, Boston, MA, June 5-8, 1989

"A 2D Electrostatic PIC Code for the Mark III Hypercube"

R. D. Ferraro, P. C. Liewer, V. K. Decyk

Thirteenth Conference on Numerical Simulation of Plasmas, Santa Fe, New Mexico, September, 1989

"Stepping Up to Parallel Processing: Is it Worth the Hassle?"

R. Ferraro

AIAA Computers in Aerospace VII Conference and Exhibit, Monterey, CA., October 3-5, 1989

"A 2D Concurrent PIC Code for Distributed Memory Parallel Computers"

R. D. Ferraro, P. C. Liewer, V. K. Decyk

Plasma Physics Division, American Physical Society, Anaheim, CA, November 13-17, 1989

"Effect of Exact and Approximate Radiation Boundary Conditions on the Solution of Scattering Problems by Finite Element Method"

N. Jacobi, T. Cwik

IEEE Antennas and Propagation and URSI Joint Meeting, San Jose, CA, June 26-30, 1989

### **Patents and New Technology Reports**

"Balanced-Load Real-Time Multiprocessor System"

R.D. Rasmussen, R.M. Manning, B.F. Lewis, G.S. Bolotin, R.S. Ward  
NASA Tech Brief NPO-17185

"The Mark III Hypercube Ensemble Computers"

J. Peterson, J. Tuazon, D. Lieberman, M. Pniel  
NASA Tech Brief NPO-16772

"The Hyperswitch Network for the Hypercube Computer"

E. Chow, H. Madan, J. Peterson  
NASA Tech Brief NPO-16905

## Neural and Analog Computing

### Publications

"Electronic Hardware Implementations of Neural Networks"

A.P. Thakoor, A. Moopenn, J.L. Lamb, S.K. Khanna  
Applied Optics 26, 5085 (1987)

"Neural Network Based Feed-Forward High Density Associative Memory"

T. Daud, A. Moopenn, J.L. Lamb, R. Ramesham, A.P. Thakoor  
IEEE, Proc. International Electron Devices Meeting, IEDM-87, 107 (December, 1987)

"Programmable, Synaptic Chips for Electronic Neural Networks"

A. Moopenn, H. Langenbacher, A.P. Thakoor, S.K. Khanna  
"Neural Information Processing Systems," Ed. D.Z. Anderson, AIP, NY (1988), p. 564

"A Neural Network for Euclidean Distance Minimization"

A. Moopenn, A.P. Thakoor, T. Duong  
IEEE Second International Conference on Neural Networks, Vol. II, 349 (1988)

"Feed-Forward, High Density, Programmable, Read-Only Neural Network Based Memory System"

T. Daud, A. Moopenn, J.L. Lamb, A.P. Thakoor, S.K. Khanna  
SPIE Proc. on High Speed Computing, Vol. 880, 76, 1988

"Design Considerations for Analog Hardware Implementation of Delta Backpropagation"

S. Eberhardt, R. Tawel, A. Moopenn  
Proceedings of the Conference on Neural Networks for Computing, Snowbird, UT, April 6-10, 1988

"Neural Networks for Robotic Control"

R. Tawel, S. Eberhardt, A.P. Thakoor  
Proceedings of the Conference on Neural Networks for Computing, Snowbird, UT, April 6-10, 1988

"Thin-Film Electrochemical Solid-State Nonvolatile Reprogrammable Resistor for Electronic Neural Networks"

R. Ramesham, S. Thakoor, T. Daud, A. Moopenn, A.P. Thakoor, S.K. Khanna  
Proceedings of the 7th Symposium on Plasma Processing, Electrochemical Soc., Atlanta, GA, May 15-20, 1988

"Considerations for Hardware Implementation of Neural Networks"

S. Eberhardt, A. Moopenn, A. Thakoor  
Conference Record of the Twenty-Second Asilomar Conference on Signals, Systems and Computers, Vol. II, 649 (1988)

"Neural Solutions to Robotic Tasks and Their Hardware Implementation"

R. Tawel, A.P. Thakoor  
Proceedings of the International Neural Network Society, Boston, MA, September 6-10, 1988

"Manganese Oxide Microswitch for Electronic Memory Based on Neural Networks"  
R. Ramesham, T. Daud, A. Moopenn, A.P. Thakoor, S.K. Khanna  
J. Vac. Sci. Technol. B7(3), 450 (1989)

"Design of Parallel Hardware Neural Network Systems from Custom Analog VLSI  
'Building Block' Chips"  
S. Eberhardt, T. Duong, A. Thakoor  
IJCNN International Joint Conference on Neural Networks, Vol. II, pp. 183-190 (1989)

"Does the Neuron 'Learn' Like the Synapse?"  
R. Tawel  
Advances in Neural Information Processing Systems, 1989 (Morgan Kaufmann  
Publishers, Inc., San Mateo)

"Custom VLSI and Thin Film Devices for Electronic Neural Nets"  
A. Moopenn, A.P. Thakoor  
Proc. IEEE 3rd Annual Parallel Processing Symp., Vol. 1, 1989, pp. 245-256

"Neural Network Hardware Solution to the Inverse Kinematic Problem in Robotics"  
R. Tawel and A.P. Thakoor  
Proceedings of the IEEE Third Annual Processing Symposium, Fullerton, CA, March 29-  
31, 1989

"Digital-Analog-Hybrid Neural Simulator: A Design-Aid for Custom-VLSI Neurochips"  
A. Moopenn, A.P. Thakoor, T. Duong  
Proc. SPIE Conf. High-Speed Computing, Vol. 1058, 1989, p. 147-157

"A VLSI Analog Synapse 'Building Block' Chip for Hardware Neural Network  
Implementations"  
S. Eberhardt, T. Duong, A. Thakoor  
Proceedings of the Third Annual Parallel Processing Symposium, Vol. I, pp. 257-267  
(1989)

"Programmable Synaptic Devices for Electronic Neural Nets"  
A. Moopenn, A.P. Thakoor  
Proceedings of the IASTED Int'l Conf. on Expert Systems and Neural Networks,  
Honolulu, HI, August, 1989

## **Presentations**

"Considerations for Hardware Implementations for Neural Networks"  
S. Eberhardt, A. Moopenn, A. Thakoor  
*Invited* presentation, Twenty-second Asilomar Conference on Signals, Systems and  
Computers, Vol. II, 649 (1988)

"Thin-Film Electrochemical Solid-State Nonvolatile Reprogrammable Resistor for  
Electronic Neural Networks"  
R. Ramesham, S. Thakoor, T. Daud, A. Moopenn, A.P. Thakoor, S.K. Khanna  
Proceedings of the 7th Symposium on Plasma Processing, Electrochemical Soc., Atlanta,  
GA, May 15-20, 1988



"Neural Solutions to Robotic Tasks and Their Hardware Implementation"

R. Tawel, A. P. Thakoor

*Invited* presentation, Conference of the International Neural Network Society, Boston, MA, September 6-10, 1988

"Neural Network Implementations and Application"

A. P. Thakoor

*Invited* presentation, TRW, Redondo Beach, CA, November, 1988

"Neural Network Architectures for Sensor Fusion"

T. Daud, A. Moopenn, Silvio Eberhardt

2nd National Symposium on Sensors and Sensor Fusion, Orlando, FL, March 27-31, (1989)

"Application of Feedback Neural Net Hardware to Cross Country Mobility Computation"

N. Bryant, T. Logan, A. Moopenn, N. Ritter, A. Thakoor

Third Tri-Service Data Fusion Symposium, Laurel, MD, May 16-18, 1989

"Electronic Implementations of Neural Networks"

A. P. Thakoor

*Invited* presentation, AVS-CSMT Open House, JPL, January, 1989

"Electronic Neuroprocessors"

A. P. Thakoor

*Invited* presentation, Hughes Aircraft Company, Newport Beach, CA, March 1989

"Electronic Neural Networks"

A. P. Thakoor

*Invited* presentation, SDIO/IST Workshop on Sensor Signal Processing, Arlington, VA, April, 1989

"Modifiable Synapses for Electronic Neural Networks"

A. P. Thakoor

NSF/ONR-sponsored workshop on Electronic Neural Nets, San Diego, CA, January, 1988

"Electronic Neural Nets and Solid State Devices"

A. P. Thakoor

*Invited* seminar, University of Pennsylvania, PA, January, 1988

"Electronic Neural Networks Based on Amorphous Silicon"

A. P. Thakoor

*Invited* paper, March, Meeting of American Physical Society, New Orleans, LA, March, 1988

"Neural Networks for Analog Processing"

A. P. Thakoor

*Invited* seminar, Case Western Reserve University, Cleveland, OH, April, 1988

"Adaptive Neurons and Analog Synapses"

A. P. Thakoor

Workshop on Artificial Neural Networks, Livermore, CA, June, 1988

"Programmable, Variable Resistor with Memory (Memistor) for Electronic Neural Networks"  
S. Thakoor, R. Ramesham, T. Daud, A. Moopenn, A.P. Thakoor  
American Physical Society Meeting, New Orleans, Louisiana, March, 1988, Bull. Am. Phys. Soc. 33, 444, (1988)

"Electronic Neural Network with Optically Modulated, Variable Strength Resistive A-Si:H Interconnects for Analog Computation"  
S. Thakoor, A. Moopenn, A.P. Thakoor  
Materials Research Society Meeting, Reno, NV, Final Program, pp. 75, April, 1988

### **Patents and New Technology Reports**

"Electronic Neurocomputer"  
A.P. Thakoor, A. Moopenn  
NASA Tech Brief, Vol. 12, No. 1, p. 12

"Programmable Synaptic Arrays for Electronic Neural Networks"  
A.P. Thakoor, J. Lambe  
NASA Tech Brief NPO-16674, U. S. Patent No. 4,876,668

"Blanket Gates for Memory Block Addressing"  
J. Lambe, A. Moopenn, A.P. Thakoor  
NASA Tech Brief NPO-16682

"Integrated Circuit for Simulation of Neural Network"  
A.P. Thakoor, A. Moopenn, S.K. Khanna  
NASA Tech Brief NPO-17059

"Electronic Neural Networks for Memory"  
J. Lambe, A. Moopenn, A.P. Thakoor  
NASA Tech Brief NPO-16680

"Electronic Neural-Network Simulator"  
A. Moopenn, A.P. Thakoor, J. Lambe  
NASA Tech Brief NPO-17058, U. S. Patent No. 4,807,168

"Memory Switches Based on Reactively Sputtered  $M_nO_{2-x}$  Thin Films"  
R. Ramesham, A.P. Thakoor, J. Lambe  
NASA Tech Brief NPO-17377 (patent pending)

"Solid-State, Programmable, Nonvolatile Reversible, Variable Resistor"  
R. Ramesham, S. Thakoor, T. Daud, A.P. Thakoor  
NASA Tech Brief NPO-17398, U. S. Patent No. 4,839,700

"Thin Film Implementation of Neural Network Based, High Density Associative Memory"  
A. Moopenn, T. Daud, A.P. Thakoor  
NASA Tech Brief NPO-17405, U. S. Patent No. 4,839,859

"Porous Gate, Field-Effect Transistor with Programmable Analog Memory"  
A. Moopenn, A.P. Thakoor, J. Lambe  
NASA Tech Brief NPO-17532 (patent pending)

"Programmable, Non-volatile, Analog Memory Based on Double-Stacked-Gate, Field Effect Transistor"

A. Moopenn, A.P. Thakoor  
NASA Tech Brief NPO-17627

"High Speed Image Classification Based on Parallel Readout of Signature Vector"

S. Thakoor, A.P. Thakoor  
NASA Tech Brief NPO-17690

"Programmable Once 'Quantized Grey Scale,' Thin Film Synapses for Electronic Neural Networks"

J.L. Lamb, T. Daud, A.P. Thakoor  
NASA Tech Brief NPO-17579

"Analog Hardware for Delta-Backprop Neural Network"

S. Eberhardt  
NASA Tech Brief NPO-17564 (patent pending)

"Design of Parallel Hardware Neural Network Systems from Custom Analog VLSI 'Building-Block' Chips"

S. Eberhardt  
NPO-17833

"Analog Hardware for Learning Neural Networks"

S. Eberhardt  
NPO-17664

"Dedicated Processor for Solving Global Allocation Problems"

S. Eberhardt and A. Moopenn  
NASA Tech Brief NPO-17781

"Dedicated Processor for Finding Lowest-Cost Map Path"

S. Eberhardt  
NASA Tech Brief NPO-17716

"Electronic Neural Network to Solve the Traveling Salesman Problem"

A.P. Thakoor and A. Moopenn  
NPO-17807

"Electrically and Optically Addressed, Ferroelectric Non-Volatile Analog Memory Adapted as Synapses in Neural Networks"

S. Thakoor, A. Moopenn and H.L. Stadler  
NPO-17973

## Neural and Nonlinear Theory

### Publications

"Neural Networks, Orientations of the Hypercube and Algebraic Threshold Functions"

P. Baldi

IEEE Trans. IS-34, pp. 523-530, 1988

"How Sensory Maps Could Enhance Resolution Through Arrangements of Broadly Tuned Receivers"

P. Baldi (with W. Heiligenberg)

Biological Cybernetics, Vol. 59 (4, 5), pp. 313-318, 1988

"Group Actions and Learning for a Family of Automata"

P. Baldi

Journal of Computer and System Sciences, 36 (2), pp. 1-15, 1988

"Neural Networks, Acyclic Orientations of the Hypercube and Set of Orthogonal Vectors"

P. Baldi

SIAM Journal of Discrete Mathematics, 1 (1), 1988

"Neural Networks and Principal Component Analysis: Learning from Examples without Local Minima"

P. Baldi (with K. Hornik)

Neural Network, Vol. 2, No. 1, pp. 53-58, 1988

"Asymptotic Normality of Some Graph Related Statistics"

P. Baldi (with Y. Rinott)

Journal of Applied Probability, Vol. 26, pp. 171-175 (1989)

"On Normal Approximations of Distributions in Terms of Dependency Graphs"

P. Baldi (with Y. Rinott)

Annals of Probability, Vol. 17, 1989

"A Normal Approximation for the Number of Local Maxima of a Random Function on a Graph"

P. Baldi (with Y. Rinott and C. Stein)

Probability, Statistics and Mathematics: Papers in Honor of Samuel Karlin, T.W. Anderson, K.B. Athreya, D.L. Iglehart, Editors, Academic Press (1989)

"Neural Networks and Principal Component Analysis: Landscapes and Algorithms"

P. Baldi

Proceedings of the Conference on Neural Information Processing, Denver, CO, Morgan Kaufman Publishers, pp. 65-72 (1989)

"Recurrent Backpropagation and the Dynamical Approach to Adaptive Neural Computation"

F.J. Pineda

Neural Computation, Vol. 1, pp. 161-172 (1989)

- "Terminal Attractors for Addressable Memory in Neural Networks"  
M. Zak  
Physics Letters A, Vol. 133, pp. 18-22, 1988
- "Dynamical Response to Pulse Excitations in Large Space Structures"  
M. Zak  
Springer Series in Comp. Mechanics, Large Space Structures and Control, 1988
- "Terminal Attractors in Neural Networks"  
M. Zak  
Neural Networks, Vol. 2, pp. 259-274, 1989
- "The Least Constraint Principle for Learning in Neurodynamics"  
M. Zak  
Physics Letters A, Vol. 135, pp. 25-28, 1989
- "Non-Lipschitzian Dynamics for Neural Net Modelling"  
M. Zak  
Appl. Math. Letters, Vol. 2, No. 1, pp. 69-72, 1989
- "Chaos as a Part of Logical Structure in Neurodynamics"  
M. Zak  
Appl. Math. Letters, Vol. 2, No. 2, pp. 175-177, 1989
- "Unsupervised Learning in Neurodynamics Using Example-Interaction Approach"  
M. Zak  
Appl. Math. Letters, Vol. 2, No. 3, pp. 281-286, 1989
- "Spontaneously Activated Systems in Neurodynamics"  
M. Zak  
Complex Systems 3, 1989
- "Weakly Connected Neural Nets"  
M. Zak  
Appl. Math. Letters, 1989
- "Neural Networks with Creative Dynamics"  
M. Zak (with J. Barhen)  
Mathematical Modelling '89, 1989
- "Analysis of Turbulence in Shear Flows Using the Stabilization Principle"  
M. Zak  
Math. and Computer Modelling, 1989
- "Hydrodynamics Stability and Frames of Reference"  
M. Zak  
Math. and Computer Modelling, 1989
- "Optical Pseudocolor Image Enhancement with Real-Time Layer Screen Display"  
H.K. Liu (with T.H. Chao)  
Opt. Engr. 27, pp. 393-398, 1988

- "Infrared Predetection Dynamic Range Compression Via Photorefractive Crystals"  
H.K. Liu (with L.F. Cheng)  
Appl. Opt. 27, 1006-1008, 1988
- "On the Progress of the Liquid Crystal Television Spatial Light Modulator"  
H.K. Liu (with T.H. Chao)  
OSA 1988 Tech. Digest Series 8, pp. 138-141, 1988
- "Real-Time Optical Edge Enhancement Using a Hughes Liquid Crystal Light Valve"  
H.K. Liu (with T.H. Chao)  
OSA 1988 Tech. Digest Series 8, pp. 35-37, 1988
- "Liquid Crystal Television Spatial Light Modulators"  
H.K. Liu (with T.H. Chao)  
Appl. Opt., Vol. 28, pp. 4772-4780, 1989
- "Rotational Invariant Holographic Tracking System"  
H.K. Liu  
Proc. SPIE, Vol. 1053, No. 155-158, 1989
- "Optical Pattern Recognition and Associative Memory: An Introduction by the Feature Editor"  
H.K. Liu  
Appl. Opt., Vol. 28, pp. 217-219, 1989
- "Real-Time Optical Holographic Tracking of Multiple Objects"  
H.K. Liu and T.H. Chao  
Appl. Opt., Vol. 28, pp. 226-231 1989
- "Machine Parts Recognition Using a Trinary Associative Memory"  
H.K. Liu (with A.A.S. Awwal and M.A. Karim)  
Opt. Engr., Vol. 28, pp. 537-543, 1989
- "Optical Pattern Recognition", Vol. 1053  
H. K. Liu, Editor  
Proceedings of SPIE (The International Society for Optical Engineering)
- "Associative Memory: An Optimum Binary Neuron Representation"  
H. K. Liu, A. A. S. Awwal, M. A. Karim  
Proc. SPIE, Vol. 1053, p. 17, 1989
- "Rotational Invariant Holographic Tracking System"  
H. K. Liu, J. L. Lamb, et. al.  
Proc. SPIE, Vol. 1053, pp. 155-158, 1989
- "Inner Layer Retinal Loss in Complicated Migraines"  
T. Lawton (with L. Dubois and A. Sadun)  
Arch. Ophthalmology, Vol. 106, pp. 1036-1037, 1988
- "Improved Word Recognition for Observers with Age-Related Maculopathies Using Compensation Filters"  
T. Lawton  
Clinical Vision Sciences, Vol. 3, pp. 125-135, 1988

"Monotonic Compensation Filters Optimize Word Recognition for Observers with Age-Related Maculopathies"

T. Lawton

In: Noninvasive Assessment of the Visual System Technical Digest Series, pp. 30-33, 1988

"Velocity Discrimination on Simple and Complex Backgrounds Predicted by a Gradient Model"

T. Lawton

Optic News, Vol. 14, p. 208, 1988

"Improved Reading Speed Using Individualized Compensation Filters for Observers with Losses in Central Vision"

T. Lawton

In: Noninvasive Assessment of the Visual System, Technical Digest Series, pp. 68-71, 1989

"Improved Reading Speed Using Individualized Compensation Filters for Observers with Losses in Central Vision"

T. Lawton

Ophthalmology, Vol. 96, pp. 115-126, 1989

"Outputs of Paired Gabor Filters Summed Across Background Frame of Reference Predicts Direction of Movement"

T. Lawton

IEEE Transactions on Biomedical Engineering, Vol. 36, pp. 130-139, 1989

"A Class of Parallel Algorithms for Computation of the Manipulator Inertia Matrix"

A. Fijany, A.K. Bejczy

IEEE Trans. RA-5, pp. 600-615, 1989

"An Efficient Algorithm for Computation of the Manipulator Inertia Matrix"

A. Fijany, A.K. Bejczy

J. Rob. Syst., Vol. 7 (in press 1989)

"A Class of Parallel Algorithms for Computation of the Manipulator Inertia Matrix"

A. Fijany, A. K. Bejczy

IEEE Int. Conf. on Robotics and Automation, pp. 1818-1826, IEEE Press, 1989

"An Efficient Method for Computation of the Manipulator Inertia Matrix"

A. Fijany, A.K. Bejczy

Proc. IEEE Int. Conf. on Robotics and Automation, pp. 1366-1373, IEEE Press, 1989

"On the Stability Storage Capacity and Design of Nonlinear Continuous Neural Networks"

J. Barhen (with A. Guez)

IEEE Trans., SMC-18, pp. 80-87, 1989

"Application of Concurrent Neuromorphic Algorithms for Autonomous Robots"

J. Barhen (with W.B. Dress)

Adv. Stud. Inst., F41, pp. 321-333, 1989

"Neural Learning of Constrained Nonlinear Transformations"

J. Barhen (with S. Gulati, M. Zak)

IEEE Computer, Vol. 22, No. 6, pp. 67-76, 1989

"The Pebble Crunching Model for Dynamic Load Balancing in Homogeneous Computation Ensembles"

J. Barhen (with S. Iyengar, S. Gulati)  
Computer Journal, 31 (1989)

"Fast Neural Learning Algorithms"

J. Barhen (with S. Gulati)  
Neural Computation, 2 (1989)

"Self-Organizing Neuromorphic Architectures for Manipulator Inverse Kinematics"

J. Barhen (with S. Gulati)  
Adv. Stud. Inst., F47 (1989)

"The Pebble Crunching Model for Load Balancing in Concurrent Hypercube Ensembles"

S. Gulati, J. Barhen, S. Iyengar  
Procs., Third Conference on Hypercube Concurrent Computers and Applications, Vol. 1, pp. 189-199, Pasadena, CA, 1988

"Smelting Networks for Cooperative Planning in the Presence of Uncertainties"

S. Iyengar, S. Gulati, J. Barhen  
Procs. IEEE Conference on Artificial Intelligence Applications, CAIA-IV, pp. 720-732, Orlando, FL, 1988

"A Comparison Study of Optimization Methods for Bipartite Matching Problems"

M. Goldstein, N. Toomarian, J. Barhen  
Procs. IEEE Second International Conference on Neural Networks, pp. II. 267-273, San Diego, CA, 1988

"Advances in Neural Network Theory with Applications to Multitarget Tracking"

J. Barhen  
Joint Institute for Defense Analysis, Strategic Defense Initiative Select Panel on Advanced Concepts, Alexandria, VA, December 13, 1988

"Real-Time Neuromorphic Algorithms for Inverse Kinematics of Redundant Manipulators"

J. Barhen, S. Gulati, M. Zak  
SPIE-1002, pp. 686-696, 1989

"Chaotic Relaxation Neurodynamics in Concurrently Asynchronous Neural Networks"

J. Barhen, S. Gulati  
IJCNN'89, Vol. 1, pp. 619-626, 1989

"Computational Theory for Learning Nonlinear Mappings"

J. Barhen, S. Gulati  
Neural Information Processing System '89, Morgan Kaufman publishers (1989)

"Fast Neural Learning Algorithms Using Networks with Non-Lipschitzian Dynamics"

J. Barhen, M. Tak, S. Gulati  
Procs. 2nd Int. Symp. on Neural Networks, pp. 55-68, Paris, France, 1989

"Adjoint Operator Algorithms for Learning in Neural Networks"

J. Barhen, N. Toomarian  
Procs. IJCNN '90 (1989)



## **Presentations**

"On Properties of Networks of Neuron-Like Elements: Complexity and Capacity"

P. Baldi

IEEE Conference on Neural Information Processing Systems (Denver, 1988)

"Unsupervised Learning Using Velocity Field Approach"

M. Zak

NIPS Proceedings, Denver, 1989

"Optical Pattern Recognition", Vol. 1053

H. K. Liu, Editor

Proceedings of SPIE (The International Society for Optical Engineering)

"Associative Memory: An Optimum Binary Neuron Representation"

H. K. Liu, A. A. S. Awwal, M. A. Karim

Proc. SPIE, Vol. 1053, pp. 17, 1989

"Rotational Invariant Holographic Tracking System"

H. K. Liu, J. L. Lamb, et. al.

Proc. SPIE, 1053, 155-158, 1989

"Vector-Matrix Multiplication Using Photorefractive GaAs"

H. K. Liu, L. J. Cheng, D. Liu

Proc. of CLEO, Baltimore, MD, May, 1989

"A Class of Parallel Algorithms for Computation of the Manipulator Inertia Matrix"

A. Fijany, A. K. Bejczy

IEEE Int. Conf. on Robotics and Automation, Scottsdale, AZ, May, 1989

"An Efficient Method for Computation of the Manipulator Inertia Matrix"

A. Fijany, A. K. Bejczy

Proc. IEEE Int. Conf. on Robotics and Automation, Scottsdale, AZ, May, 1989

"Parallel Algorithms and Architecture for Computation of Manipulator Inverse Dynamics"

A. Fijany, A. K. Bejczy

Proc. of the Fourth Int. Conf. on Advanced Robotics (ICAR), Columbus, OH, June, 1989

"The Pebble Crunching Model for Load Balancing in Concurrent Hypercube Ensembles"

S. Gulati, J. Barhen, S. Iyengar

Procs. Third Conferences on Hypercube Concurrent Computers and Applications, Vol. 1, pp. 189-199, Pasadena, CA, 1988

"Smelting Networks for Cooperative Planning in the Presence of Uncertainties"

S. Iyengar, S. Gulati, J. Barhen

Proc. IEEE Conference on Artificial Intelligence Applications, CAIA-IV, pp. 720-732, Orlando, FL, 1988

"A Comparison Study of Optimization Methods for Bipartite Matching Problems"

M. Goldstein, N. Toomarian, J. Barhen

Proc. IEEE Second International Conference on Neural Networks, pp. II. 267-273, San Diego, CA, 1988

"Advances in Neural Network Theory with Applications to Multitarget Tracking"

J. Barhen

Joint Institute for Defense Analysis, Strategic Defense Initiative Select Panel on Advanced Concepts, Alexandria, VA, December 13, 1988

"Real-Time Neuromorphic Algorithms for Inverse Kinematics of Redundant Manipulators"

J. Barhen, S. Gulati, M. Zak

SPIE-1002, pp. 686-696, 1989

"Chaotic Relaxation Neurodynamics in Concurrently Asynchronous Neural Networks"

J. Barhen, S. Gulati

IJCNN '89, Vol. 1, pp. 619-626, 1989

"Computational Theory for Learning Nonlinear Mappings"

J. Barhen, S. Gulati

Neural Information Processing System '89, Morgan Kaufman publishers (1989)

"Fast Neural Learning Algorithms Using Networks with Non-Lipschitzian Dynamics"

J. Barhen, M. Tak, S. Gulati

Proc. 2nd Int. Symp. on Neural Networks, pp. 55-68, Paris, France, 1989

"Adjoint Operator Algorithms for Learning in Neural Networks"

J. Barhen, N. Toomarian

Proc. IJCNN '90 (1989)

## **Patents and New Technology Reports**

"Chaotic Motion of a Two-Link Planar Mechanism"

M. Zak

NASA Tech. Brief NPO-17387

"Dispersion, Damping and Confinement of Propagating Pulses in Large Space Structures"

M. Zak

NASA Tech Brief NPO-17559

"Non-Lipschitzian Dynamics for Modeling Neural Networks"

M. Zak

NASA Tech Brief NPO-17814

"Characteristic Wave Approach as a Complement to Model Analysis"

M. Zak

NASA Tech Brief NPO-17741

"Hydrodynamic Stability and Frames of References"

M. Zak

NASA Tech Brief NPO-17740

"Determining Sense of Motion in Robotic Vision"

T. Lawton

NASA Tech Brief NPO-17552

"Image Enhancement Aid for the Partially Sighted"

T. Lawton

NASA Tech Brief NPO-17307

"Efficient Jacobian Inversion for the Control of Simple Robot Manipulators"

A. Fijany, A. K. Bejczy

NASA Tech Brief NPO-17544

"Parallel Processing Algorithms for Dynamics of Manipulators"

A. Fijany, A. K. Bejczy

NASA Tech Brief NPO-17718

"An Efficient Method for Computation of the Manipulator Inertia Matrix"

A. Fijany, A. K. Bejczy

NASA Tech Brief NPO-17545

"ARASH-URCS: A Parallel Architecture for Robotics"

A. Fijany, A. K. Bejczy

NASA Tech Brief NPO-17632 (patent pending)

"URRCS: A Highly Parallel Architecture for a Universal Robotic Real-Time Controller and Simulator"

A. Fijany, A. K. Bejczy

NASA Tech Brief, NPO-17629 (patent pending)

# Optical Processing

## Publications

"Optical Correlators with Fast Updating Speed Using Photorefractive Semiconductor Materials"

G. Gheen, L.J. Cheng

Applied Optics, Vol. 27, p. 2756 (1988)

"Matrix-Vector Multiplication in Thin Photorefractive GaAs Crystals"

L.J. Cheng, G. Gheen

Applied Optics, Vol. 27, p. 4236 (1988)

"Photorefractive GaAs as an Optical Processing Medium"

L.J. Cheng, G. Gheen

Technical Digest of the Conference on Lasers and Electro-Optics, Anaheim, CA, April 25-29, 1988, p. 328

"Optical Pseudocolor Image Enhancement with Real-Time Large Screen Display"

T.H. Chao, H.K. Liu

Opt. Eng. Vol. 27, pp. 393 (1988)

"Real-Time Optical Edge Enhancement Using a Hughes LCTV"

T.H. Chao, H.K. Liu

Technical Digest of the Conference on Spatial Light Modulation and Applications, Lake Tahoe, NV, June 15-17, 1988 (Optical Society of America, Washington, D.C.) p. 35

"Optical Pseudocolor Image Enhancement with Real-Time Large Screen Display"

T.H. Chao, H.K. Liu

Opt. Eng. Vol. 27, p. 393 (1988)

"High Speed Parallel Optical Processors of Photorefractive Semiconductors"

L.J. Cheng, D.T.H. Liu

Technical Digest of the Topical Conference on Optical Computing, Salt Lake City, UT, February 28-March 2, 1989, Vol. 9, p. 87

"Hybrid Vision of the Automated Spacecraft Landing"

R. Juday, T.H. Chao

Proc. SPIE, Vol. 1053, p. 131 (1989)

"Real-Time Optical Holographic Tracking of Multiple Objects"

T.H. Chao, H.K. Liu

Appl. Opt. Vol. 28, p. 226 (1989)

"Auto- and Hetero-Associative Memory Using a 2-D Optical Logic Gate"

T.H. Chao

Proc. SPIE Vol. 1053, p. 60 (1989)

"Real-Time Optical Holographic Tracking of Multiple Objects"

T.H. Chao, H.K. Liu

Appl. Opt. Vol. 28, p. 226, (1989)

## **Presentations**

"Hybrid Vision of Automated Spacecraft Landing"

R. Juday, T.H. Chao  
Proc. SPIE, Vol. 1053, p. 131 (1989)

"Auto- and Hetero-Associative Memory Using a 2-D Optical Logic Gate"

T. H. Chao  
"Optical Pattern Recognition," Proceedings of SPIE, Vol. 1053, p. 60 (1989)

"Limitations of Opto-Electronic Neural Networks"

J. Yu, D. Psaltis, A.R. Johnston  
"Optical Pattern Recognition," Proceedings of SPIE, Vol. 1053, p. 40 (1989)

"Optical Versus Electronic Implementations of Neural Networks"

J. Yu, D. Psaltis, D. Brady  
Neural Networks for Computing, Snowbird, UT, April, 1989

"Rotational Invariant Holographic Tracking System"

J. Lambe, G. Gheen, T. Chao, A.R. Johnston, H.K. Liu  
Proc. SPIE, Vol. 1053, p. 155 (1989)

"Matrix-Vector Operations Using Four-Wave Mixing in GaAs"

L.J. Cheng, G. Gheen, D.T.H. Liu, H.K. Liu  
Conference on Lasers and Electro-Optics, Baltimore, MD, April 24-28, 1989

## **Patents and New Technology Reports**

"Real-Time Pseudocolor Enhancement of an Image"

T.H. Chao, H.K. Liu  
NASA Tech Brief NPO-17139 (patent pending)

"Matrix-Vector Multiplication in Thin Photorefractive Semiconductor Crystals"

L. J. Cheng, G. O. Gheen  
NASA Tech Brief NPO-17455

"Optical Processing Using Photorefractive Compound Semiconductors"

L. J. Cheng  
NASA Tech Brief NPO-17533

"Optical Signal Using the Photorefractive Effects in Semiconductor Etalons"

L. J. Cheng, A. Partovi, E. M. Garmire  
NASA Tech Brief NPO-17460

"Achromatical Optical Correlator"

T. H. Chao, H. K. Liu  
NASA Tech Brief NPO-17206

"Optical Processing With Photorefractive Semiconductors"

L. J. Cheng, G. Gheen  
NASA Tech Brief NPO-17324

"Dynamic Range Compression/Expansion of Light Beams by Photorefractive Crystals"

L.J. Cheng, H.K. Liu

NASA Tech Brief NPO-17140, U. S. Patent No. 4,772,785

"Remotely Controllable Real-Time Optical Processor"

H.K. Liu

NASA Tech Brief NPO-16750, U. S. Patent No. 4,772,101

"Real-Time Image Difference Detection Using a Polarization Rotation Spatial Light Modulator"

T.H. Chao, H.K. Liu

NASA Tech Brief, NPO-17144

## **Data Storage**

### **Publications**

"Model for Demagnetization-Induced Noise in Thin-Film Magnetic Recording Media"  
R. R. Katti, V. V. Veeravalli, M. H. Kryder, B. V. K. Kumar  
IEEE Transactions on Magnetics, Vol. 24, No. 4, pp. 2150-2158, July, 1988

"Computer Simulation of Gates for Ion-Implanted Devices"  
M. Alex, J.C. Wu, M.H. Kryder  
IEEE Transactions on Magnetics, Vol. 24, No. 6, pp. 3114-3116, November, 1988

"Computer Simulated Model of Thermomagnetic Writing"  
R. Weng, J.C. Wu, Z.J. Cendes, M.H. Kryder  
IEEE Transactions on Magnetics, Vol. 25, No. 5, pp. 3536-3538, September, 1989

### **Presentations**

"Vertical Bloch Line Memory"  
H. L. Stadler  
Air Force Space Command SDI Group, Los Angeles Air Force Base, March 24, 1989

"Vertical Bloch Line Memory"  
H. L. Stadler  
SDI Contractors Meeting, Los Angeles Air Force Base, June 5, 1989

"Results of Spaceflight Data Storage Study"  
R. R. Katti  
Data Systems Technology Working Group Meeting, NASA Civil Space Technology Initiative, Goddard Space Flight Center, Greenbelt, MD, June 15, 1989

"Memory and Magnetic Memory Concepts"  
R. R. Katti and H. L. Stadler  
JPL/Caltech Workshop for New Organic Electronic, Optical, and Magnetic Materials, Pasadena, CA, June 19, 1989

"Vertical Bloch Line Memory"  
H. L. Stadler  
Non-Volatile Memory Conference, Baltimore, MD, August 9, 1989

"Comparison of VBL Memory Architecture"  
J. C. Wu and H. L. Stadler  
4th Workshop on Vertical Bloch Lines and Micromagnetic Memories, University of Wuppertal, Wuppertal, West Germany, September 11, 1989

"Noise Models in Magnetic Recording"  
R. R. Katti  
Electrical Engineering Seminar, Caltech, Pasadena, CA, January 26, 1989

"Spaceflight Data Storage Technology"

H. L. Stadler

*Invited* presentation, Electrical Engineering Graduate Seminar, Carnegie Mellon University, Pittsburgh, PA, November 2, 1989

"Computer Simulation of Gates for Ion-Implanted Devices"

M. Alex, J.C. Wu, M.H. Kryder

IEEE Transactions on Magnetics, Vol. 24, No. 6, pp. 3114-3116, November, 1988

### **Patents and New Technology Reports**

"High Speed Magnetoresistive Random Access Memory"

J. C. Wu, H. L. Stadler, R. R. Katti

NPO-17954

"Integrated, Nonvolatile, High Speed, Analog Random Access Memory"

R. R. Katti

NPO-17998

"Photochromic Recording Process and Media"

R. R. Katti, D. Coulter

NPO-18010



## **Molecular Computation**

### **Publications**

"Electronic Shift Register Memory Based on Molecular Electron Transfer Reactions"

D.N. Beratan, J.J Hopfield, J.N. Onuchic

J. Phys. Chem., Vol. 93, p. 6350 (1989)

"Information Storage at the Molecular Level: the Design of a Molecular Shift Register Memory"

D. N. Beratan, J. N. Onuchic, J. J. Hopfield

Journal of the British Interplanetary Society, Vol. 42, p. 468 (1989)

"The Influence of Gap States on the Non-Resonant Second Hyperpolarizabilities of Conjugated Organic Polymers"

D.N. Beratan

J. of Phys. Chem., Vol. 93, p. 3915 (1989)

### **Presentations**

"A Molecular Shift Register Memory Based on Electron Transfer"

D. N. Beratan

10th Course of the International School of Pure and Applied Biostructure of the Ettore Majorana Center, Erice, Sicily, Italy, December, 1988

"Design of a True Molecular Electronics Device: The Electron Transfer Shift Register Memory"

D. N. Beratan

Engineering Foundation Conference on "Molecular Electronics -- Science and Technology" Keauhou Kona, Hawaii, February, 1989

### **Patents and New Technology Reports**

"Molecular Implementation of a Molecular Shift Register Based on Electron Transfer"

J. N. Onuchic, D. N. Beratan

NASA Tech Brief NPO-17606

"Molecules with Enhanced Electronic Polarizabilities Based on 'Defect'-Like States in Conjugated Polymers"

D.N. Beratan

NPO-17633 (patent pending)

"All Optical Photochromic Spatial Light Modulators"

D.N. Beratan, J.W. Perry

NASA Tech Brief NPO-17612



## Overview

The goals of this program are to develop custom microcircuit technology, also known as Application Specific Integrated Circuits (ASICs) technology, for use in flight and ground programs. Supporting this effort are activities to investigate the effects of the space environment, and particularly ionizing radiation, on microcircuits and to develop a space qualification methodology. Another aspect of the program emphasizes innovative applications of custom microcircuit technology to image and signal processing and communications.

## 1988-1989 Major Technical Achievements

### Application Specific Integrated Circuits

- **Fabricated** Direct Memory Access Coprocessor through MOSIS for system testing. First silicon received in August 1989, tested and found to be 100% functional. System testing on the Mariner Mark II spacecraft breadboard computer is underway.
- **Designed and submitted** for fabrication a Silicon Controller chip which will control 21 gallium arsenide phase shifter chips in a 2-dimensional, 21-element phased array antenna system.
- **Demonstrated** a floating gate field effect transistor with analog memory in VLSI using double-poly process (MOSIS), a strong contender as a synapse for electronic neural networks with on-chip learning capability.
- **Designed and fabricated** a wide spectrum of cascable, programmable, CMOS/VLSI synaptic chips with binary to 11-bit resolution, as well as multi-neuron chips. This has led to transfer of neural net hardware technology to U.S. industries.
- **Developed** "building blocks" for high speed image processing and pattern recognition applications. The building blocks consist of:
  - **A fabricated** 62x62 thin film, binary, nonvolatile, programmable, high density synaptic array with a nominal feature size of 2 microns based on amorphous chromium silicon alloy system.
  - **A designed and fabricated** 64-neuron CMOS/VLSI "winner-take-all" cascable chip with a winner lockout feature. It selects the best pattern match in less than 10 microseconds (with an effective search rate of more than  $10^9$  bits/sec for a 64-bit x1000 word memory).
- **Fabricated and successfully tested** player-detector chip for Army-funded Simulation of Area Weapons Effects (SAWE) program.
- **Developed** VLSI design of a universal noiseless coder for the Image Spectrometer of Flight Processor (ISFLIP).
- **Developed** VLSI design of systolic tree-search vector quantizer for Eos on-board SAR processor.

- **Designed** two versions of a custom chip for the Big Viterbi Decoder (BVD) and the Deep Space Network (DSN):
  - A standard cell device, produced through United Technologies Microelectronics Center (UTMC)
  - A gate array device, produced through VLSI Technology Inc. (VTI)
- **Developing** flight qualifiable designs for two custom VLSI chips supporting the MAX multicomputer.
- **Demonstrated** Hyperswitch Adaptive Message Routing VLSI chip with a data throughput per channel of 400 Mbits/s and adaptive network reconfiguration for a number of random channel failures. The above tests were verified with a laboratory testbed configuration.
- **Developing** a custom VLSI chip (300,000 transistors) and overall system for the Human Genome Project. This biological system will have the performance of over 40 Cray-2 supercomputers at 1/1,000 of the cost.
- **Designed** complete VLSI memory chips (with I/O) using Vertical Bloch Line (VBL) pairs as memory elements, for use with nonvolatile, radiation hard magnetic garnet technology. Fabrication is proceeding under contract on devices with 10 Mbit/cm<sup>2</sup> and 25 Mbit/cm<sup>2</sup> densities. Test chips have been designed and fabricated (and are undergoing testing) for evaluating operation of the storage cells (i.e., minor loops). Magnetostatic performance simulations were conducted for VBL output detector and major line gates (i.e., output gates).

### **Quality Assurance and Space Qualification Methodology**

- **Designed and tested** 4k CMOS SRAM to characterize SEU susceptibility of CMOS process. Performed SEU testing at Berkeley 88-inch cyclotron. Demonstrated that the LET upset threshold can be adjusted via external offset voltage to allow bench-level SEU testing using an alpha particle source.
- **Developed** new technique for determining and controlling temperature in multi-segment interconnect electromigration test structures under stress.
- **Designed** four chip set to evaluate reliability and defect clustering for 2-micrometer CMOS p-well Wafer Scale Integration process.
- **Fabricated** set of JPL test chips (including Total Ionizing Dose Chip, Fault Chip and Reliability Chip) alongside JPL designed Direct Memory Access Coprocessor chip. These chips are to provide support for flight qualification of the DMAC.
- **Received** "Best Paper" award at 1989 International Conference on Microelectronic Test Structures. Presented timing sampler results, characterizing signal propagation delay.

## Application Specific Integrated Circuits

### Publications

"A VLSI Design for Universal Noiseless Coding"

J. Lee, W. Fang, R. Rice

SPIE Proceedings, Los Angeles, CA, January, 1988

"A VLSI Design of a Pipeline Prime Factor DFT over Finite Design"

T. K. Truong, I. S. Hsu, H. C. Shyu, I. S. Reed, H. M. Shao

IEEE Trans. on Acoustics, Speech and Signal Processing, Vol 37, No. 3, March, 1988

"A Comparison of VLSI Architecture of Finite Multipliers Using Dual, Normal or Standard Bases"

T. K. Truong, I. S. Reed, L. J. Deutsch

IEEE Trans. on Computers, Vol. 37, No. 3, June 3, 1988

"A VLSI Architecture for Performing Finite Field Arithmetic with Reduced Table Lookup"

I. S. Hsu, T. K. Truong, I. S. Reed, N. Glover

Linear Algebra and Its Applications, Edited by I.F. Blake, Elsevier Science Publishing Co., Inc., 1988

"A Long Constraint VLSI Viterbi Decoder for the DSN"

J. Statman, G. Zimmerman, F. Pollara, O. Collins

TDA Progress Report 42-95, Jet Propulsion Laboratory, Pasadena, CA, July - September, 1988

"A New VLSI Architecture for a Single-Chip-Type Reed-Solomon Decoder"

I.S. Hsu, T.K. Truong

TDA Progress Report 42-96, Jet Propulsion Laboratory, Pasadena, CA, October - December, 1988

"On Testing VLSI Chips for the Big Viterbi Decoder"

I. Hsu

TDA Progress Report 42-96, Jet Propulsion Laboratory, Pasadena, CA, October - December, 1988

"Test Aspects of the JPL Viterbi Decoder"

M. Breuer

TDA Progress Report 42-96, Jet Propulsion Laboratory, Pasadena, CA, October - December, 1988

"Data Compression for on-board SAR Processor"

C. Chang, W. Fang, J. Curlander

IGARSS'89 Proceedings, Vancouver, Canada, July, 1989

"A VLSI Design of Systolic Tree-Search Vector Quantizer for Eos On-Board SAR Processor"

W. Fang, C.Y. Chang, S.Y. Kuo, R.H. Nixon, J.C. Curlander

Government Microcircuit Applications Conference (GOMAC) Proceedings, Kissimmee, FL, November, 1989

## **Presentations**

"Data Compression for On-Board SAR Processor"

C. Chang, W. Fang, J. Curlander

IGARSS'89, Vancouver, Canada, July, 1989

"A VLSI Design of Systolic Tree-Searches Vector Quantizer for Eos On-Board SAR Processor"

W. Fang, C.Y. Chang, S.Y. Kuo, R.H. Nixon, J.C. Curlander

Government Microcircuit Applications Conference (GOMAC), Kissimmee Florida, November, 1989

"A VLSI Design for Universal Noiseless Coding"

J. Lee, W. Fang, R. Rice

SPIE, Los Angeles, CA, January, 1988

## **Patents and New Technology Reports**

"A Large Constraint Length High Speed Viterbi Decoder"

O. Collins, S. Dolinar, I. Hsu, E. Olson, F. Pollara, J. Statman, G. Zimmerman

NASA Tech Brief NPO-17639 (patent pending)

"Programmable DMA Controller"

D. Hendry

NASA Tech Brief NPO-17341 (patent pending)

"A VLSI Single Chip (255, 223) Reed-Solomon Encoder with Interleaver"

I.S. Hsu, T.K. Truong, L.J. Deutsch, I.S. Reed

NASA Tech Brief NPO-17280 (patent pending)

"A New VLSI Architecture for the Viterbi Decoder of Large Constraint Length Convolutional Codes"

I.S. Hsu, T.K. Truong, J. Sun, I.S. Reed

NASA Tech Brief NPO-17310 (patent pending)

"A Comparison of VLSI Architectures for Time and Transformation Domain Decoding of Reed-Solomon Codes"

I.S. Hsu, T.K. Truong, L.J. Deutsch, E. Satorius, I.S. Reed

NPO-17510

# Quality Assurance and Space Qualification Methodology

## Publications

"A Direct Method for Measuring the Gate Oxide Capacitances of MOSFETs"

R.A. Allen, C.A. Pina, M.G. Buehler

Proceedings of the 1988 International Conference on Microelectronic Test Structures, February, 1988

"Comparison of Results from Simple Expressions for MOSFET Parameter Extraction"

M.G. Buehler, Y.-S. Lin

Proceedings of the 1988 International Conference on Microelectronic Test Structures, February, 1988

"CMOS Process Monitor"

M.G. Buehler, L.W. Linholm, V.C. Tyree, et. al.

Proceedings of the 1988 International Conference on Microelectronic Test Structures February, 1988

"Comb/Serpentine/Cross-Bridge Test Structure for Fabrication Process Evaluation

H.R. Sayah, M.G. Buehler

Proceedings of the 1988 International Conference on Microelectronic Test Structures February, 1988

"Temperature Control in Wafer-Level Testing of Large Multi-Segment Electromigration Test Structures"

N. Zamani, Y.-S. Lin

Proceedings of the 1988 International Conference on Microelectronic Test Structures February, 1988

"Fast and Accurate Wafer-Level Measurement of Temperature Profile in Multi-Segment Electromigration Test Structures"

M.G. Buehler

Proceedings of 1988 VHSIC/VLSI Qualification, Reliability, and Logistics Workshop

"A CMOS Matrix for Extracting MOSFET Parameters Before and After Irradiation

B.R. Blaes, M.G. Buehler, Y.-S. Lin, K.A. Hicks

IEEE Trans. Nucl. Sci. NS-35 (1988)

"New Flange Correction Formula Applied to Interfacial Resistance Measurements of Ohmic Contacts to GaAs"

U. Lieneweg, D.J. Hannaman

IEEE Electron Dev. Lett. 8 (1988)

"Inverter Propagation Delay Measurements using Timing Sampler Circuits

B.R. Blaes, M.G. Buehler

Proc. IEEE Inter. Conf. on Microelectronic Test Structures, Vol 2, No 1, March, 89

"Parameter Distributions for Complex VLSI Circuits"

M.G. Buehler, B.R. Blaes, H.R. Sayah, U. Lieneweg

Proceedings of the Decennial Caltech Conference on VLSI, 20-22 March, 1989

"Chip-Level Electromigration Measurement Technique for Multi-Segmented Interconnect Test Structures"

N. Zamani, J. Dhiman, M.G. Buehler

Proc. Sixth Int. IEEE Multilevel Interconnect Conference (1989)

"Radiation Dependence of Inverter Propagation Delay From Timing Sampler Measurements"

M.G. Buehler, B.R. Blaes, Y.-S. Lin

accepted for publication in IEEE Trans. Nucl. Sci. NS-36, December, 1989

## **Presentations**

"A Direct Method for Measuring the Gate Oxide Capacitances of MOSFETs"

R.A. Allen, C.A. Pina, M.G. Buehler

Proceedings of the 1988 International Conference on Microelectronic Test Structures, February, 1988

"Comparison of Results from Simple Expressions for MOSFET Parameter Extraction"

M.G. Buehler and Y.-S. Lin

1988 International Conference on Microelectronic Test Structures, February, 1988

"CMOS Process Monitor"

M.G. Buehler, L.W. Linholm, V.C. Tyree, et. al.

1988 International Conference on Microelectronic Test Structures, February, 1988

"Comb/Serpentine/Cross-Bridge Test Structure for Fabrication Process Evaluation

H.R. Sayah, M.G. Buehler

1988 International Conference on Microelectronic Test Structures, February, 1988

"Temperature Control in Wafer-Level Testing of Large Multi-Segment Electromigration Test Structures"

N. Zamani, Y.-S. Lin

1988 International Conference on Microelectronic Test Structures, February, 1988

"Fast and Accurate Wafer-Level Measurement of Temperature Profile in Multi-Segment Electromigration Test Structures"

M.G. Buehler

VHSIC/VLSI Qualification, Reliability, and Logistics Workshop, 1988

"Parameter Distributions for Complex VLSI Circuits

M.G. Buehler, B.R. Blaes, H.R. Sayah, U. Lieneweg

Decennial Caltech Conference on VLSI, 20-22 March, 1989

"Parametric Wafer FET and PCM Testing"

M.G. Buehler, D.J. Hannaman

GaAs IC Symposium Short Course on GaAs IC Testing, October, 1989

"Inverter Propagation Delay Measurements using Timing Sampler Circuits

B.R. Blaes, M.G. Buehler

Proc. IEEE Inter. Conf. on Microelectronic Test Structures, Vol 2, No 1, March, 89



## **Patents and New Technology Reports**

**"Formula Gives Better Contact-Resistance Values"**

U. Lieneweg, D.J. Hannaman  
NASA Tech Briefs NPO-17096

**"Combined Comb Step-Coverage and Cross Bridge Resistor"**

H. Sayah, M. G. Buehler  
NASA Tech Brief NPO-17393

**"Timing Sampler for Delay Measurements"**

B. R. Blaes, M. G. Buehler  
NASA Tech Brief NPO-16645, U. S. Patent No. 4,688,947

**"Measuring Critical Charges for Single Event Upset Phenomena"**

B. R. Blaes, M. G. Buehler  
NASA Tech Brief NPO-17073

**"System Measures Logic-Gate Delays"**

B. R. Blaes  
NASA Tech Brief NPO-16646

## **Algorithms Tailored for ASIC Designs**

### **Publications**

"Real-Time Data Compression for Eos-class Missions"

J. Lee, W. Fang, R. Rice

EASCON Proceedings, Washington DC, October, 1987

"A Simplified Procedure for Correcting Both Errors and Erasures of Reed-Solomon Code"

T.K. Truong, W.L. Eastman I.S. Reed, I.S. Hsu

IEEE Proceedings, Vol 135, Pt E, No 6, November, 1988

"Functional Design of Data Compression Algorithms"

C.Y. Chang, J. Bowers, W. Fang

JPL Publication, D-6459 (JPL internal document), Jet Propulsion Laboratory, Pasadena, CA, June, 1989

"Fourier Analysis and Signal Processing by use of the Mobius Inversion Formula"

I.S. Reed, T.K. Truong, D.W. Tufts, M.T. Shih, X. Yin, X. Yu

IEEE Trans. on Acoustics, Speech and Signal Processing, (to be published) 1989

"Optional High Rate Systematic Convolutional Codes for Rates 3/4, 4/5, 6/7"

J. Sun, T.K. Truong, I.S. Reed, H.E. Huey

IEEE Proceedings, (to be published) 1989

"A Fast Transform Decoding of Nonsystematic Reed-Solomon Codes"

A. Shiozaki, T.K. Truong, K.M. Cheung, I.S. Reed

IEEE Proceedings, Part E, (to be published) 1989

"A Simplified Procedure for Decoding the (23,12) Golay Code"

X.W. Yin, T.K. Truong, I.S. Reed, J.K. Holmes

IEEE Proceedings, Part E, (to be published) 1989

"Wiring Viterbi Decoders (Splitting DeBruijn Graphs)"

O. Collins, Follara, S. Dolinar, J. Statman

TDA Progress Report 42-96, Jet Propulsion Laboratory, Pasadena, CA

### **Presentations**

"Real-Time Data Compression for Eos-Class Missions"

J. Lee, W. Fang, R. Rice

EASCON Proceedings, Washington DC October, 1987

"VLSI Implementation of GSC Architecture with a New Ripple Carry Adder"

I.S. Reed, B. Sharona, M.T. Shih, J. Bailey, T.K. Truong.

IEEE Conference on Computer Design: VLSI in Computers and Processors, Port Chester, New York, October 3-5, 1988

"Suppression of Narrowband Interference"

E. Satorius, S. Krishnan, X.L. Yu, L.J. Griffiths, I.S. Reed

Twenty-second Asilomar Conference on Signals, Systems and Computers, Monterey, CA, October 31 - November 2, 1988

## **Patents and New Technology Reports**

"A Simplified Procedure for Correcting Both Errors and Erasures of Reed-Solomon Codes"

T.K. Truong, W.L. Eastman, I.S. Reed, I.S. Hsu  
NASA Tech Brief NPO-17381



## CSMT-Caltech Campus Collaboration (Cumulative List)

T. Phillips	Submillimeter Detectors
D. Rutledge	Submillimeter Antennas
G. Fox	Hypercube Concurrent Computing
P. Messina	Hypercube Concurrent Computing
J. Hopfield	Neural Networks, Molecular Computation
C. Koch	Neural Networks
D. Psaltis	Optical Processing
J. D. Baldeschweiler	Scanning Tunneling Microscopy
F. Culick	Robotic Computing
K. Vahala	E-Beam Lithography
D. Goodstein	High Tc Superconductivity
R. Housely	High Tc Superconductivity
M. Cross	High Tc Superconductivity
D. Dougherty	Optical Switching Materials
A. Yariv	Infrared Detectors
H. Gray	Molecular Electronics
A. Zewail	Optical Characterization
R. Grubbs	Nonlinear Optical Materials
N. Yeh	High Tc Superconductivity
J. Pine	Micromachined Silicon Biological Probes
L. Hood	Custom VLSI for Genome Sequencing

## **Distinguished Visiting Scientists (Cumulative List)**

- Professor Albert W. Overhauser, Department of Physics, Purdue University
  - Chaired Professor
  - Member NAS
  - Buckley Prize Winner (1975)
- Professor Hadis Morkoc, Department of Electrical Engineering and Material Research Laboratory, University of Illinois
  - MBE semiconductor devices
- Dr. Robert Jaklevic, Principal Research Scientist, Ford Motor Co., Research Staff
  - Inventor of Superconducting Quantum Interference Devices (SQUID)
  - Inventor of Inelastic Electron Tunneling Spectroscopy
- Dr. C. Thomas Elliot, Royal Signals and Radar Establishment, United Kingdom
  - Leading international expert on IR technology
  - Inventor of the Sprite (Signal Processing in Element) detector
- Professor Lester Eastman, Electrical Engineering, Cornell University
  - Fellow of the IEEE
  - Member of the U.S. Government Advisory Committee on Electron Devices
  - Member National Academy of Engineering
- Professor Max Schultz, Department of Applied Physics, University of Erlangen, West Germany
  - Infrared imaging
  - Semiconductor interface characterization and silicon MBE
  - MOS physics
- Professor John Wilkins, Department of Physics, Cornell University
  - Solid state theory of metals, superconductors and semiconductors
- Professor O. Engstrom, Department of Solid State Electronics, Chalmers University of Technology, Gothenburg, Sweden
  - Energy properties of solid memory cells

- Professor Pieter Balk, Delft Institute of Technology, Delft, The Netherlands
  - Director of the Delft Institute of Microelectronics and Submicron Technology
  - MBE of III-V materials and SiGe
  - MOS physics
- Professor Floyd Humphrey, Department of Electrical Engineering, Boston University, Massachusetts
  - Magnetic mass random access memory
  - Microsecond optical studies of magnetic switching
  - 1988 IEEE Magnetics Society Achievement Award
- Professor C.D.W. Wilkinson, Department of Electronics and Electrical Engineering, University of Glasgow, United Kingdom
  - Nanometer electron beam lithography
- Dr. T. Andersson, Department of Physics, Chalmers University, Sweden
  - MBE of III-V materials
  - Interface formation in thin films
- Professor N. Farhat, Department of Electrical Engineering, University of Pennsylvania
  - Optical neural networks
  - Photonics
- Professor James Mayer, Department of Materials Science and Engineering, Cornell University
  - Francis Norwood Bard Professor of Materials Science and Engineering
  - RBS/channeling and ion beam modification of materials
  - Interdiffusion and reactions in thin films
- Professor L. Eric Cross, Department of Electrical Engineering, Pennsylvania State University
  - Former Director of Materials Research Laboratory
  - Ferroelectric thin films polysaccharides
- Dr. John Lambe, Ford Motor Co. (retired)
  - Superconductivity
  - Neural networks
- Professor James Rosenberg, Department of Electrical Engineering, Brown University
  - Germanium IR detectors
  - High speed devices

- Dr. L. Craig Davis, Ford Motor Co.
  - Theory of ballistic electron devices
  - Electronic structure devices of semiconductors
- Professor Eric Fossum, Department of Electrical Engineering, Columbia University
  - Charge-coupled device design and physics
  - MOS physics
- Professor Leo Schowalter, Department of Physics, Rensselaer Polytechnic Institute
  - Silicon molecular beam epitaxy
  - Ballistic electron emission microscopy
- Professor James Lukens, Department of Physics, State University of New York, Stony Brook
  - Superconducting terahertz local oscillator



## **Conferences and Workshops** (Sponsored and/or Hosted by CSMT)

- Polymers in Non-linear Integrated Optics (July 24, 1986)
- Neural Network Devices and Applications (February 18-19, 1987)
- OSA Topical Conference on Machine Vision (March, 1987)
- Submillimeter (Terahertz) Receiver Technology (April 7-8, 1987)
- CLEO (April 27-May 1, 1987)
- Highly Parallel Fault-Tolerant Computers for Space Applications (June 9-10, 1987)
- International Conference on Scanning Tunneling Microscopy '87 (July 20-24, 1987)
- Congress of the International Commission for Optics (August 24-28, 1987)
- Neural Information Processing Systems - Real and Synthetic (November 8-12, 1987)
- Hypercube Concurrent Computers and Applications (January 19-21, 1988)
- Spatial Light Modulator and Applications (June, 1988)
- Microspacecraft for Space Science (July 6-7, 1988)
- Solid-State Terahertz Sources Workshop (August, 1988)
- American Vacuum Society, Southern California Section (January 1989)
- Hypercube Concurrent Computers and Applications (March, 1989)
- 1989 Space Cryogenics Workshop (July 1989)
- Technology Information Meeting - Microelectronics (November 1989)



TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. JPL Publication 90-3	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Center for Space Microelectronics Technology 1988-1989 Technical Report		5. Report Date March 1, 1990	
		6. Performing Organization Code	
7. Author(s) Peggy Olsen		8. Performing Organization Report No.	
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91109		10. Work Unit No.	
		11. Contract or Grant No. NAS7-918	
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		13. Type of Report and Period Covered  JPL Publication	
		14. Sponsoring Agency Code (c/c)B-055-80-08-00-20	
15. Supplementary Notes			
16. Abstract  The 1988-1989 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the center during the past two years. The report lists 321 publications, 282 presentations, and 140 new technology reports and patents.			
17. Key Words (Selected by Author(s))  Computer Programming and Software Infrared and Ultraviolet Detection Optics Solid-State Physics		18. Distribution Statement  Unclassified -- Unlimited	
19. Security Classif. (of this report)  Unclassified	20. Security Classif. (of this page)  Unclassified	21. No. of Pages  123	22. Price

